Numerical Propulsion System Simulation (NPSS) 1999 Industry Review

John Lytle, Greg Follen, Cynthia Naiman, Austin Evans,
Joseph Veres, Karl Owen, and Isaac Lopez
Glenn Research Center, Cleveland, Ohio

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1999 INDUSTRY REVIEW

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National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

SUMMARY

The technologies necessary to enable detailed numerical simulations of complete propulsion systems are being developed at the NASA Glenn Research Center in cooperation with industry, academia and other government agencies. Large scale, detailed simulations will be of great value to the nation because they eliminate some of the costly testing required to develop and certify advanced propulsion systems. In addition, time and cost savings will be achieved by enabling design details to be evaluated early in the development process before a commitment is made to a specific design. This concept is called the Numerical Propulsion System Simulation (NPSS). NPSS consists of three main elements: (1) engineering models that enable multi-disciplinary analysis of large subsystems and systems at various levels of detail, (2) a simulation environment that maximizes designer productivity, and (3) a cost-effective, high-performance computing platform. A fundamental requirement of the concept is that the simulations must be capable of overnight execution on easily accessible computing platforms. This will greatly facilitate the use of large-scale simulations in a design environment. This paper describes the current status of the NPSS with specific emphasis on the progress made over the past year on air breathing propulsion applications. In addition, the paper contains a summary of the feedback received from industry partners in the development effort and the actions taken over the past year to respond to that feedback. The NPSS development was supported in FY99 by the High Performance Computing and Communications Program.

Overview Presentation

John Lytle
NASA Glenn Research Center
Cleveland, Ohio

Outline

- **Background**

- **1998 Industry Feedback**

- **FY99 Status**

  - **Resource Distribution**

  - **Major Accomplishments**

- **FY00 Major Milestones**

- **Future Direction**

High Performance Computing and Communications (HPCCP)

- The main goal of the HPCCP is to accelerate the development of high-performance computers and networks and the use of these resources in the Federal Government and throughout the American economy.

- The GRC primary role in the HPCCP is through the Computational Aerosciences (CAS) Project. The goal of CAS is to accelerate the availability of high performance computing hardware and software to the United States aerospace industry for use in their design processes through the solution of *Grand Challenge* problems.

- The goal of the NREN Project is to research, develop and deploy advanced network technologies required by high performance mission applications that satisfies the needs of the researcher while guiding commercial infrastructure development for the nation.

- The goal of the LTP is to enhance the learning of math, science and engineering in the K-12 educational system through the use of computing and communications technologies and dissemination of information about the NASA missions.

CAS
Computational AeroSciences
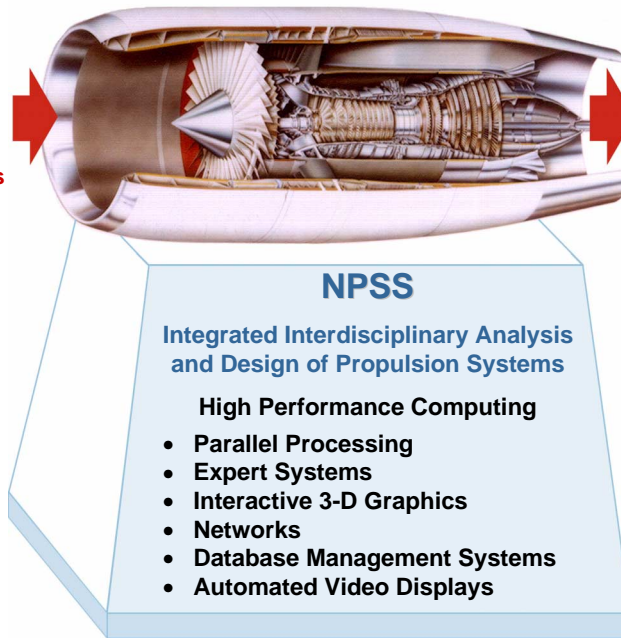
NREN
NASA Research and Education Network

LTP
Learning Technologies Project

HPCCP Gross Funding

$M — Fiscal Year
(00, 01, 02, 03, 04)
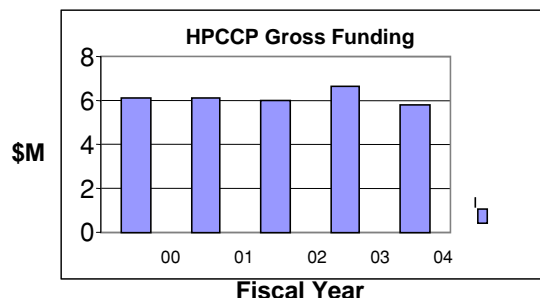
Numerical Propulsion System Simulation (NPSS)

Validated Models

- **Fluid Mechanics**
- **Heat Transfer**
- **Combustion**
- **Structural Mechanics**
- **Materials**
- **Controls**
- **Manufacturing**
- **Economics**

Rapid Affordable Computation of:

- **Performance**
- **Stability**
- **Cost**
- **Life**
- **Certification Req.**

NPSS

Integrated Interdisciplinary Analysis and Design of Propulsion Systems

High Performance Computing

- **Parallel Processing**
- **Expert Systems**
- **Interactive 3-D Graphics**
- **Networks**
- **Database Management Systems**
- **Automated Video Displays**

A Numerical Test Cell for Aerospace Propulsion Systems

97	98	99	00	01	05	10

1-D Engine (National Cycle Program)

Axisymmetric Engine

3-D Engine Steady-State Aerodynamic

3-D Engine Steady-State Multidisciplinary

3-D Engine Dynamic Multidisciplinary

3-D Low Pressure Subsystem (ADPAC)/ 1–D HP Core

3-D Engine (APNASA)/ 2–D Combustor

3-D Reacting Flow (National Combustor Code)

UG/WAVE Common Geometry

3–D High Pressure Compressor (Design Point) (APNASA)

Multistage Compressor Map

Integrated Propulsion/Airframe Simulation

NPSS
Work Breakdown Structure

Engineering Applications & Advanced Propulsion Cycles

National Cycle Program
- Axisymmetric Engine
- 3–D Subsystems/System

Component integration

High Performance, Affordable Computing

Simulation Environment

- Modular Architecture
  - National Cycle Program
- Toolkits
  - SSCD
  - CM Manager
  - CAPRI
  - MDOW
- Library/Utilities
  - NURBS
  - PEV
  - Data Standards

MD coupling

Zooming

- Coupled Aero-Thermal-Structural (CATS)
- CFD/Controls
- Spectrum
- MDICE
- MSAT

- 0–D Engine/ 1–D Inlet
- 0–D Core/3–D LP Subsystem
- 1–D Combustor/ 3–D Engine

- High-Speed Networks
- Code Parallelization
- Load Sharing Facility
- P6 Cluster
- O2K Metacenter

Overall NPSS Program Ratings

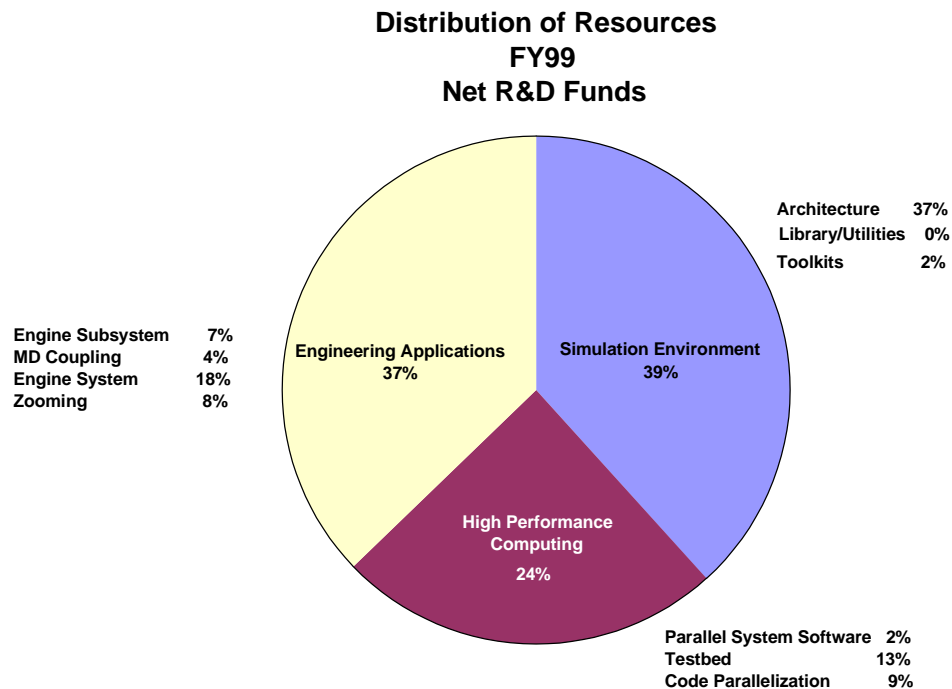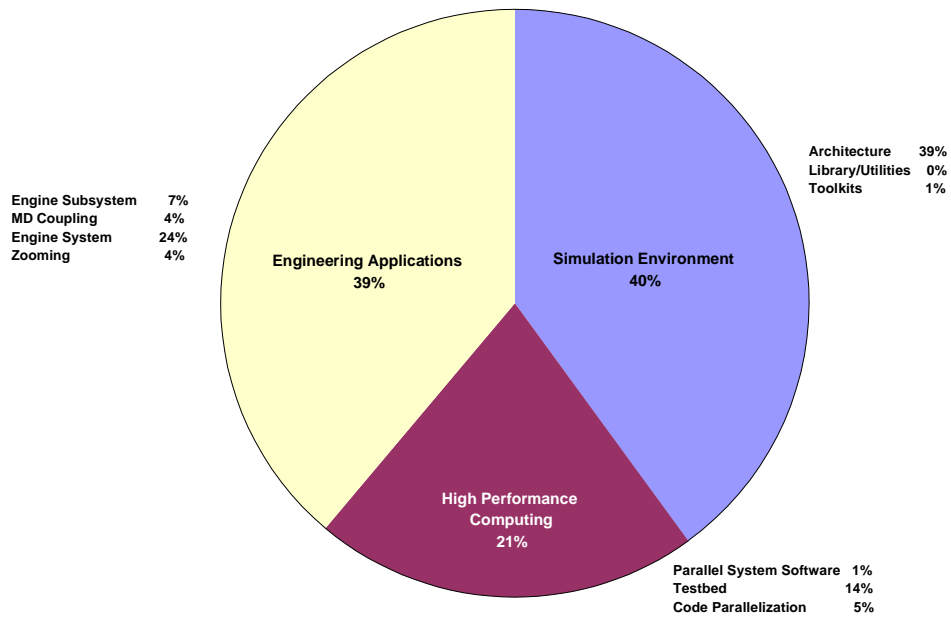| Category	FY 94	FY 95	FY 96	FY 97	FY 98
NPSS vs Other NASA Programs	9.0	7.7	8.08	8.0	8.2
Relevence to Industry	7.8	8.2	8.6	9.0	8.2
Overall Program Balance	7.3	6.3	8.1	8.1	8.6
Tech. Transfer	7.3	6.3	5.6	5.5	6.2
Industry Participation	7.7	8.8	8.1	7.5	7.4
Meeting Expectations	7.7	6.5	6.6	6.5	7.0
Survey	7.7	6.7	6.3	6.8	6.6
Overall Average	7.8	7.2	7.3	7.3	7.5
Overall Average w/o Survey	7.8	7.3	7.5	7.4	7.6
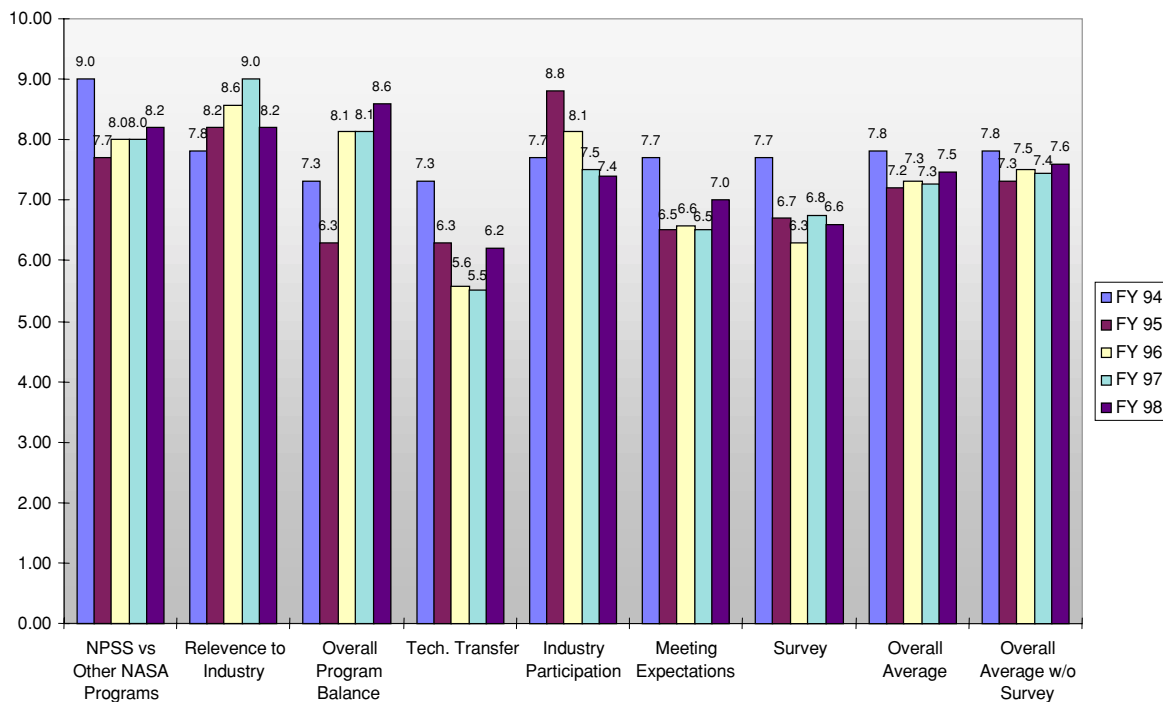
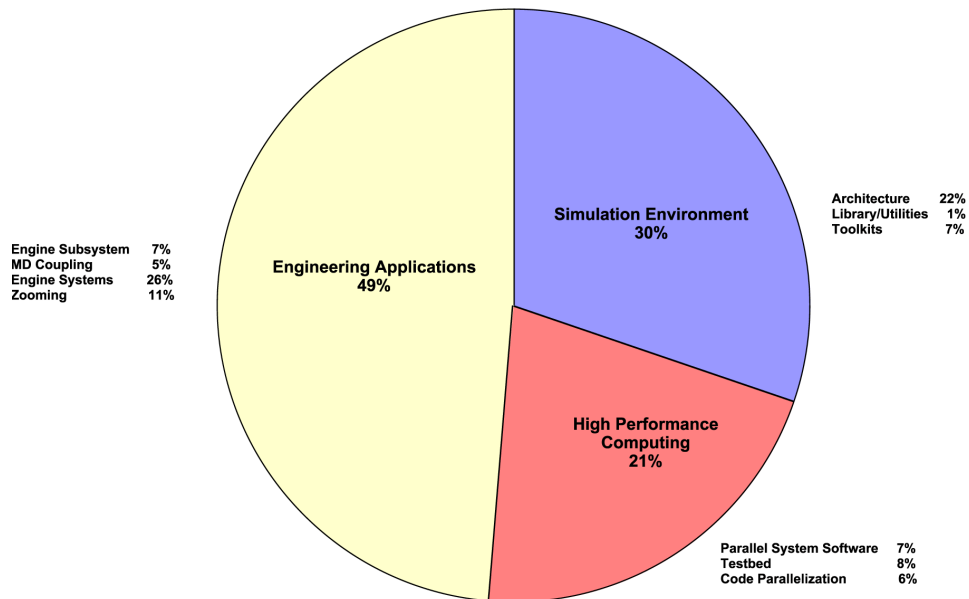# FY 98 Executive Committee Report

- Need a Visual Assembly Layer in NPSS
  - Requirement Remains Part of the NPSS Plan
  - Revisited Priority of this Requirement
  - Decision to Delay Until Greater Functionality Achieved
  - Currently Planned for NPSS Version 3 (FY 01)
- Focus on "Deliverables" and Incremental Process
  - Incremental Releases Planned for "Early Assessment"
  - Future Versions to Incorporate Broad NPSS Requirements (Not Just NCP)
  - National Cycle Program Version 1 Planned for 2nd Q FY 00
- Lack of MD/Structural Content
  - Completed the Initial Assessment of the SPECTRUM Multiphysics Code
  - Increased Investment in the Common Geometry Definition
  - Focussed Phase III Requirements Gathering **on MD Applications**

**Distribution of Resources
FY99
Net R&D Funds**

Architecture	37%
Library/Utilities	0%
Toolkits	2%

Engine Subsystem	7%
MD Coupling	4%
Engine System	18%
Zooming	8%

**Engineering Applications
37%**

**Simulation Environment
39%**

**High Performance
Computing
24%**

Parallel System Software	2%
Testbed	13%
Code Parallelization	9%

Distribution of Resources
FY99
Net R&D Funds and CS FTE

Engine Subsystem 7%
MD Coupling 4%
Engine System 24%
Zooming 4%

Engineering Applications
39%

Simulation Environment
40%

Architecture 39%
Library/Utilities 0%
Toolkits 1%

High Performance
Computing
21%

Parallel System Software 1%
Testbed 14%
Code Parallelization 5%

Distribution Of Resources
FY98
Net R&D Funds

Engine Subsystem 7%
MD Coupling 5%
Engine Systems 26%
Zooming 11%

Engineering Applications
49%

Simulation Environment
30%

Architecture 22%
Library/Utilities 1%
Toolkits 7%

High Performance
Computing
21%

Parallel System Software 7%
Testbed 8%
Code Parallelization 6%

Selected FY 99 Highlights

- Delivered an Incremental Release of NPSS in Preparation for the Version 1 Release in FY 00. Copyright Assignment to NASA Completed
- Demonstrated Significant Time Savings in Implementing the Zooming Concept through the NPSS Object-oriented Architecture
- Completed the Initial Phase of Validating Multiphysics Analysis for Turbomachinery Flows
- Demonstrated a 320:1 Reduction in Combustion Simulation Time and a 400:1 Reduction in Turbomachinery Simulation Time Relative to a 1992 baseline
- Completed the Full Combustor Simulation and the Coupled High Pressure and Low Pressure Turbine in preparation for the 3-D Primary Flowpath Engine Simulation
- Demonstrated High Computing Efficiency with the Information Power Grid Concept through an NPARC Application Running at Ames and Glenn Research Centers
- Initiated the Use of the Pentium Cluster to Execute Significant Turbomachinery Simulations in a Production Mode
- Initiated a Space Act Agreement with Stanford University to Partner on the Integration of 3-D Turbomachinery and Combustion Codes

FY 00 Major Milestones

- Deliver NPSS Version 1.0 (customer deck generation, 1-D control volume, dynamic link libraries, linear model generation,..) (2nd Q)

- Complete 3-D Primary Flowpath Simulation (4th Q)

- Complete Requirements Definition for future NPSS Production Software Releases (2nd Q)

- Couple 3-D Aero and Structural Analyses through the NPSS Architecture (4th Q)
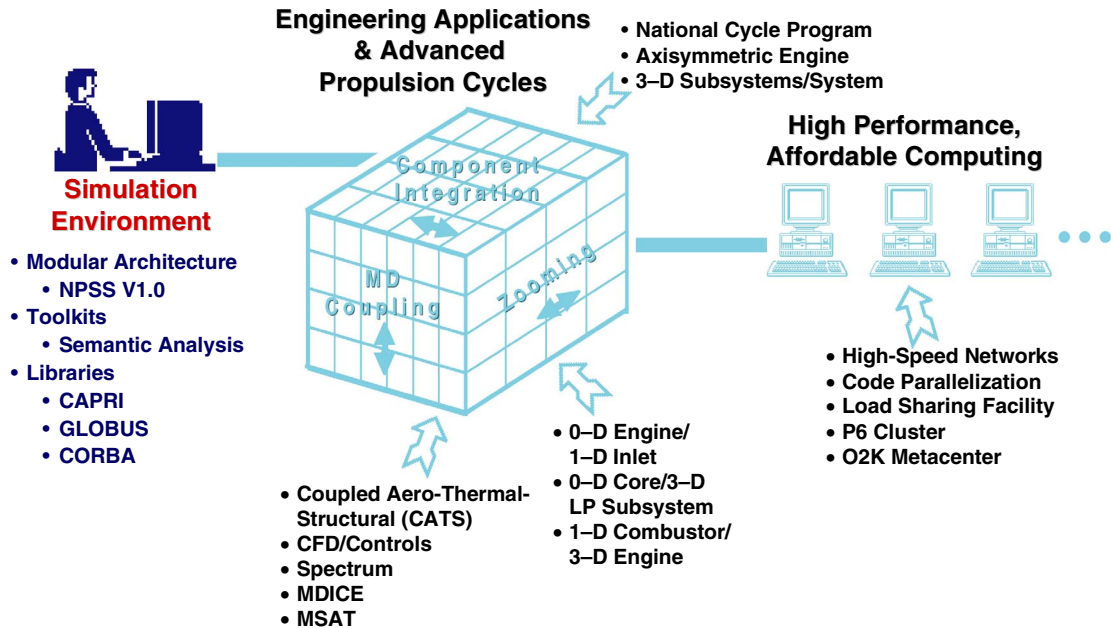
Future Direction

- Continue to Play a Strong Role in the High Performance Computing and Communications Program

- Increased Emphasis on Space Transportation and Aero-Space Synergy in the Near Term

- Alignment of Long Range Goals with Intelligent Synthesis Environment and Intelligent Systems

- Initiate New Collaborations with DOD and DOE
    – Versatile Affordable Turbine Engine (DOD)
    – Joint Strike Fighter (DOD)
    – Integrated High Performance Turbine Engine Technology (DOD)
    – Accelerated Strategic Computing Initiative (DOE)
    – Advanced Turbine Systems and Vision 21 (DOE)

Simulation Environment/Production Software

Greg Follen and Cynthia Naiman
NASA Glenn Research Center
Cleveland, Ohio

Engineering Applications & Advanced Propulsion Cycles

- National Cycle Program
- Axisymmetric Engine
- 3–D Subsystems/System

High Performance, Affordable Computing

Component Integration

MD Coupling

Zooming

Simulation Environment

- Modular Architecture
  - NPSS V1.0
- Toolkits
  - Semantic Analysis
- Libraries
  - CAPRI
  - GLOBUS
  - CORBA

- Coupled Aero-Thermal-Structural (CATS)
- CFD/Controls
- Spectrum
- MDICE
- MSAT

- 0–D Engine/ 1–D Inlet
- 0–D Core/3–D LP Subsystem
- 1–D Combustor/ 3–D Engine

- High-Speed Networks
- Code Parallelization
- Load Sharing Facility
- P6 Cluster
- O2K Metacenter

Numerical Propulsion System Simulation Environment

Agenda:

- NPSS V 1.0
  - Status
  - Zooming

- NPSS Architecture
  - Status

- New Opportunities & FY00 Plans

Objectives for Simulation Environment

- Provide flexible, extensible, and powerful framework for multidisciplinary analysis and design.

- Integrate with external codes for solving distributed code coupling and Numerical Zooming.

- Preserve company proprietary data.

- Provide a common modeling tool for U.S. Government, aerospace industry, and academia.

- Provide a catalyst for establishing new standards for interfacing with tools of different disciplines.

NPSS V 1.0 with Zooming

Flowpath Analysis

High Fidelity Analysis

Axisymmetric Engine

High Fidelity Analysis

Fan/Booster

Fan/Nacelle

Mixer Nozzle

3-D Low Pressure Subsystem

3-D High Pressure Compressor
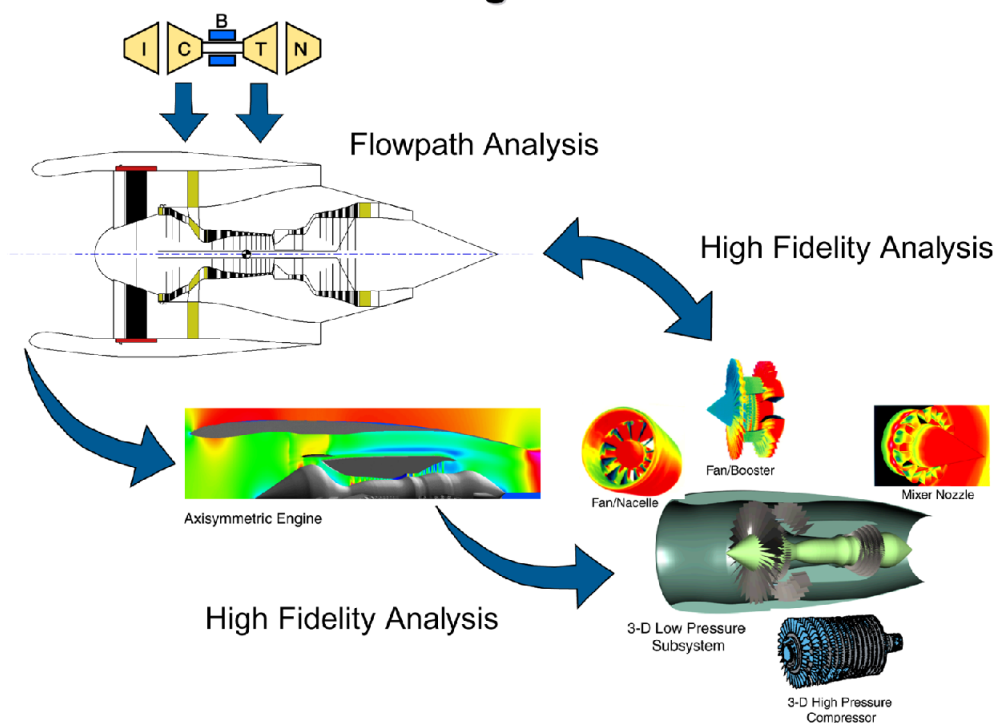
NPSS V 1.0 Topics

- FY99 Accomplishments
- NPSS Version 1
  - Schedule
  - Capabilities
- Demonstrations
  - Zooming
  - Globus
- NPSS Rockets Modeling
- Visual Based Syntax
- Current Status
- FY00 Goals

NPSS Version 1.0

Objective:

NPSS Version 1 provides an architectural framework for the Numerical Propulsion System Simulation (NPSS) project. The initial focus is on the aero thermodynamic cycle simulation process. It is a catalyst for establishing new standards for interfacing with tools of different disciplines.

Approach:

Representatives from government and the Aeropropulsion and Space industry determined that an object-oriented approach would meet and exceed the modeling and simulation requirements of the aero thermodynamic cycle simulation process while also creating an extensible framework for the NPSS system.

FY99 Accomplishments

- Requirements Signed Off November 1998

- Completed Visual Based Syntax Analysis July 1999

- Incremental Release Delivered July 1999

- Customer Evaluation and Validation September 1999

- On Schedule to Release NPSS Version 1 1st Qtr 2000

Capabilities in NPSS Version 1 Increment 1 Distributed July 1999

- Customer Deck
  - Prototype of customer deck for native API
  - Variable hiding including error handling changes
  - Infrastructure changes for Engineering Status Indicators (ESIs)
- Usability
  - Auto-Documentation, initial interactive debug
  - Improved user documents
  - NPSS training module continually updated
  - NPSS Developers Kit
- Dynamic Link Modules
  - Initial Dynamic Link Module (DLM)
  - DLM Developer's Kit (HP & Sun)

Capabilities in NPSS Version 1 Increment 1 (Continued)

- Advanced Engineering Components
  - Compressor Temp map
  - Pure substance thermo (rockets) *
  - Heat exchanger, diffuser, cross-over valve
  - Inverter valve, propeller
  - Simulating flameout, locked rotor, and windmilling and coast down
  - Shaft spring 'breakage'
  - Guess function *, GASTAB *

FY99 Accomplishments (Continued)

- Demonstrated Running NPSS using Information Power Grid (IPG) Globus Services.

- P&W Demonstrated Zooming from 0-D to 1-D High Compressor Component Code.

- Significant Advancement toward Fully Interpreted Engineering Environment.

- Allison Improved EEE Model.

- Used an EEE model and recasted to a representative model of high bypass turbofan engine and matched design points in less than a day.

FY99 Accomplishments (Continued)

- Modeled Pulse Detonation Engine (PDE) using NPSS
  - Wrapped & tested PDE analysis code within NPSS in 2 hours
  - Developed turbofan with PDE as core within a week
- Multi-point design with nested solvers demonstrated
- Propulsion System Analysis Office is using NPSS to support mainline work
- Using NPSS to support Propulsion Health Monitoring Effort of the NASA Aviation Safety Program

FY99 Accomplishments (Continued)

- Design Improved
  - Make system changes to facilitate builds
  - Decoupled therm and ports
  - Providing dynamic link modules
- Documentation Improved
  - User Guide updated based on feedback from customers
  - Drafted Programmer's Guide
- Development Environment Improved
  - Installed new machines
  - Upgraded operating systems and compilers

FY99 Accomplishments (Continued)

- Software Development Process Improved

    – Change Request Process Fine Tuned

    – Completed Regression Test Script

    – Increased involvement of test team with developers resulting in finding and fixing problems earlier

    – Formal software development processes continuously improved to facilitate technology transfer

    – Positioned well for ISO 9001 certification

- Team members attended training: C++, JAVA, CORBA, ObjectStore, Unified Modeling Language, Rational Rose, Design Patterns

NPSS Version 1 & 2 Schedule

- Acceptance Review for NPSS V1   1st Qtr '00

- Software Configuration Audits for NPSS V1   1st Qtr '00

- Full Release of NPSS V1   1st Qtr '00

- Requirements Sign Off for NPSS V2   March '00

- Incremental Release of NPSS V2   3rd Qtr '00

- Acceptance Review for NPSS V2   1st Qtr '01

- Software Configuration Audits for NPSS V2   1st Qtr '01

- Full Release of NPSS V2   1st Qtr '01

Capabilities in NPSS Version 1 Increment 2 (Full Release) to be Distributed 1st Quarter 2000

- Finish customer deck

- Preset numbering scheme (ESIs)

- Finish Interactive debug Linear Model Generation

- DLMs on all platforms

- ID-Control volume (Concluded no solver changes needed)

- Audit factors *

- Turbine temperature map

- Compressor and turbine backbone maps

- Fan, Vectoring nozzle

Capabilities in NPSS Version 1 Increment 2 (Full Release) (Continued)

- Nacelle installation, Thrust Reverser, Emissions

- Augmentor, 2-phase water

- Full interpreted release of all engineering components

- Converter enhancements to support interpreted components

- Solver Enhancements, Fixes

- Future releases will incorporate Phase II, III requirements

Zooming

Objective:

Define the NPSS object infrastructure to support for Component Zooming.

Approach:

Determine the quality and depth of the current NPSS design support for zooming by connecting the 0D engine system with a 1D component. Evaluate the NPSS zooming capabilities and proceed with a more complex zooming simulation leading to a full zooming infrastructure from 0D - 3D and any appropriate combination therein.

Zooming Examples

- P&W Zooming Demo 0-D to 1-D High Pressure Component (proprietary)

- 0-D to 2-D HTO300 Compressor

- Allison LP Simulation Use of NPSS V1.0

A Definition of NPSS Zooming:

Automated, seamless integration of one or more high resolution component analyses with the full NPSS system simulation.

NPSS Zooming Example:

Integration of a 1-Dimensional (row-by-row) Euler compression analysis code with the full NPSS 0-Dimensional engine simulation.

A Few Terms:

0-Dimensional:

Lumped Component model with no internal axial dimensionality (Typical for Engine Models)
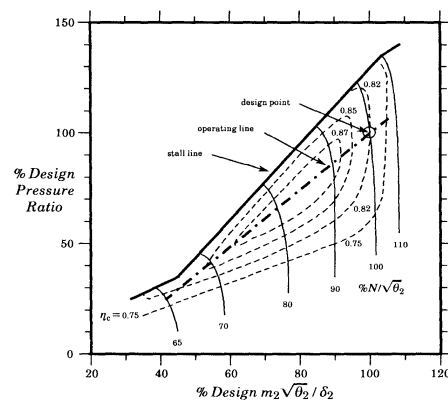
Fig. 5.5 Typical Compressor Map[12]

1-Dimensional:

Axial Component representation
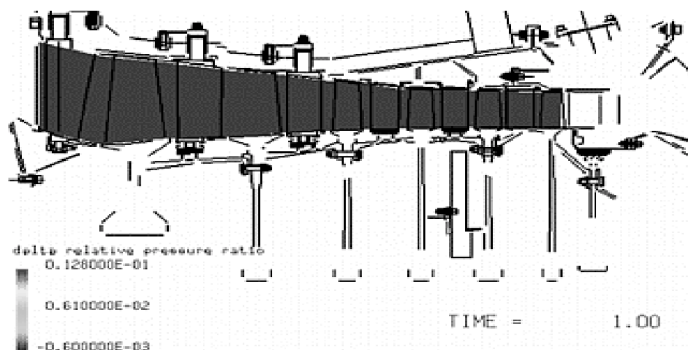
NPSS Zooming High Level Architecture

Client Processor

NPSS 0-D Engine Representation

FAN

HPC

DUCT

BURN

HPT

LPT

NOZ

Compressor 1-D Element

CORBA Legacy Code Launch S/W

◄── **Recompiled NPSS Executable** ──►

Speed, Eff = F(Tip Clearance, Vane Setting, Bleed)

1-Dimensional Compressor Meanline code
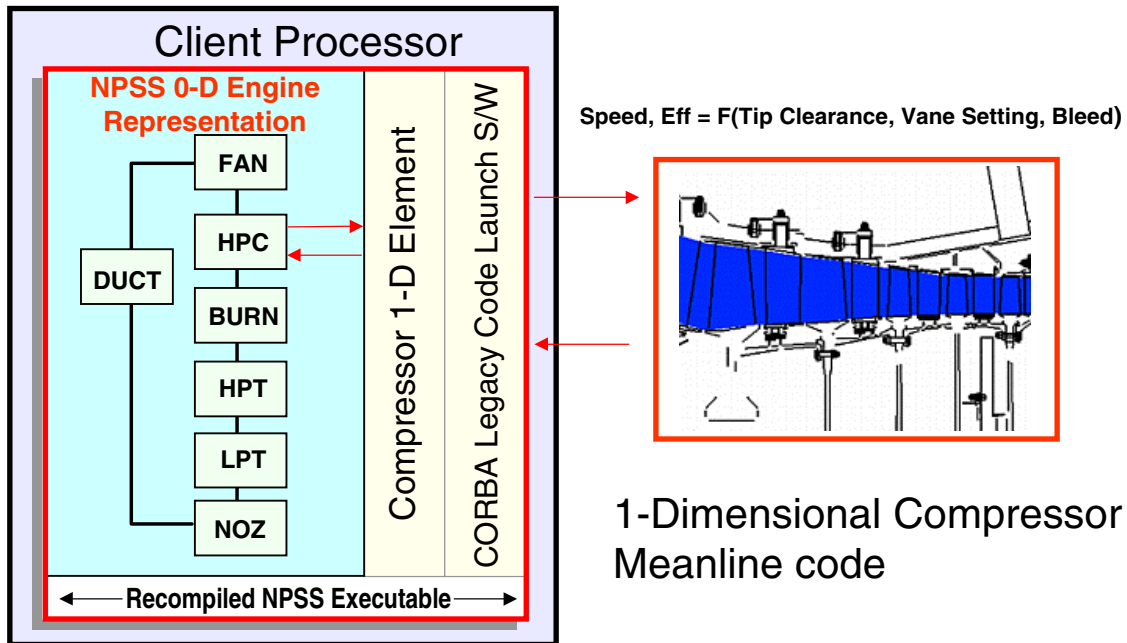
Compressor Object for NPSS Zooming

Created for Zooming

0-D NPSS Compressor Element	1-D NPSS Compressor Interface Element	CORBA Legacy Code Launch S/W	ORB	CORBA-Wrapped HPC Meanline

- Lumped HPC Map
- Standard Interconnection Infrastructure

- 0-D Scalar Calculations
- Other Zooming Calculations
- Loads Boundary Conditions for 1-D Analysis
- Starts CORBA Launcher

- Initializes CORBA Server and CPU Host
- Specifies 1-D Version
- Loads Boundary Conditions
- Launches 1-D Analysis via CORBA

- 1-D Euler Row-By-Row Meanline Compressor Model

Role of NPSS Object Oriented Architecture

▶ IT/Computing Issues Moved from the Engineer to the NPSS Zoomed Object
- *Enables Error-Free Execution* of Legacy Component Analysis
- *Increases Utilization* of "Corporate Knowledge" Represented by the Legacy Analysis

▶ Object Oriented Implementation Key Enabler Relative to Traditional Systems
- *Rapid Execution* - More Than One Component Could be Zoomed and Executed on Multiple CPU's through CORBA Communication Standard
- *Collaborative System Models* - Web Based Execution of Geographically Distributed Proprietary Analysis in Joint Venture a Practical Reality
- *Code Reuse* - NPSS Objects can be integrated with non-NPSS Analysis without redesign

Significance of Numerical Results from Zooming

▶ "What If" Analysis for Variable Vane Scheduling, Bleed or Clearance Changes Reduced from 2 Days to 2 Hours
- *No Need for "Expert"* Execution of Legacy System
- *No "handoff" of Information* from Systems Organization to Component Organizations - NPSS is the Integrator
- *Automatic Map Update* by Zooming Function Eliminates Today's Manual Process to Update the 0D Model
- *Accuracy Exceeds 0D map* since the effects of 2nd order effects not in 0-D map, but in the 1-D analysis, are influencing the NPSS system results

▶ Increased Resolution of System Model to Each Row of the HPC Enables Unprecedented Operability Analysis
- *Stage Loading at Millisecond* Intervals Available for Inspection During Engine Operational Transients
- *Coupled Effects of Variable Geometry,* Stability Bleeds, Thermals and Tip Clearances Captured at System Level

Zooming to HTO300 Compressor Code

- HTO300 is a Boeing Compressor Streamline Curvature Code (Design/Off Design)

- Developing tools to make wrapping of this and other codes faster and easier
  – 2D array variable class has been added to NPSS to handle differences between C++ and FORTRAN 2D arrays
    - Row major versus column major ordering
    - Zero versus non-zero starting index
  – Parser is being developed to extract variables from COMMON blocks and generate C++ code to make them accessible through the NPSS interpreter
    - Parser currently can generate C++ struct declarations to map to COMMONs

Zooming Between 0D NPSS Engine to 1D Compressor

0 Dimensional Map Based Analysis/Design

1/2 Dimensional Blade Row with Geometry

NPSS V1.0

P&W/HTO300

3 Dimensional CFD

FY'99

FY'00

APNASA
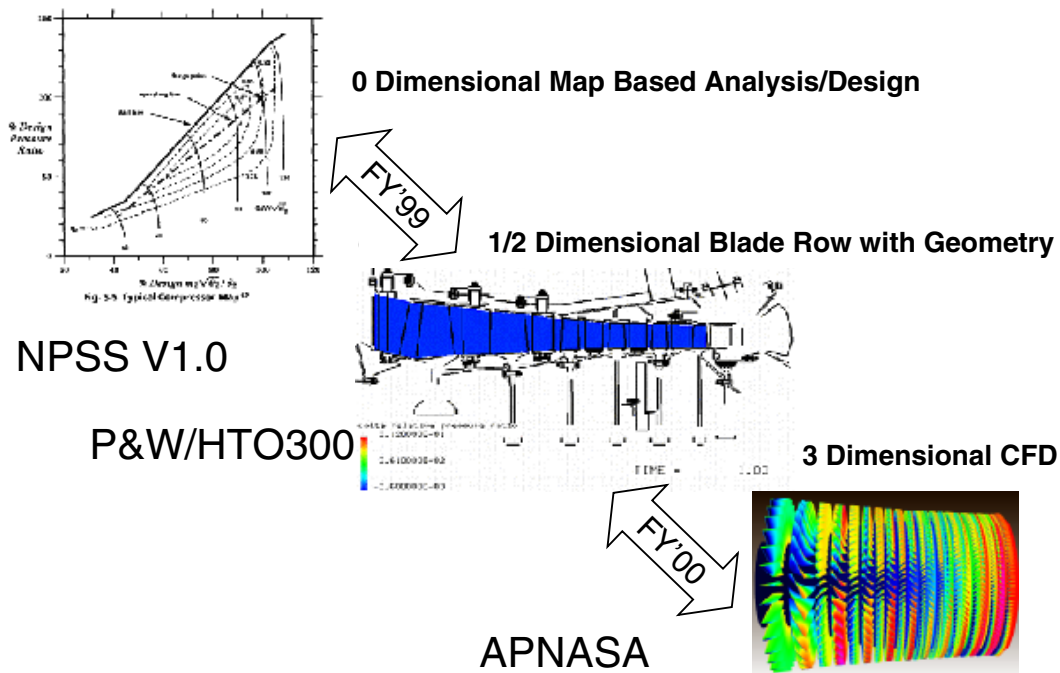
Zooming

Status:

- 0D-1D zooming was successfully demonstrated in the NPSS Architecture. HTO300 code will be integrated for general consumption by 12/1/99.

- Phase II/III team responded with a 0D-3D-3D-0D simulation as the next case to test the architecture. Codes and simulation will be determined at next Architecture onsite 11/2/99.

NPSS V.1 CORBA – Globus

GASS - Global Access to Secondary Storage
GRAM - Global Resource Allocation Manager
HTP - High Throughput Broker

Front End/GUI
(Windows NT)

COM (MS)
CORBA
GASS

CORBA

Globus Server
- Schedules
- Stages
- Runs

GRAM
GASS
HTB

CORBA

Model Info Server
- Executables
- Common Data

GASS

Glenn (SGI & Linux)
GRAM
GASS

Langley (SGI)
GRAM
GASS

Ames (SGI)
GRAM
GASS
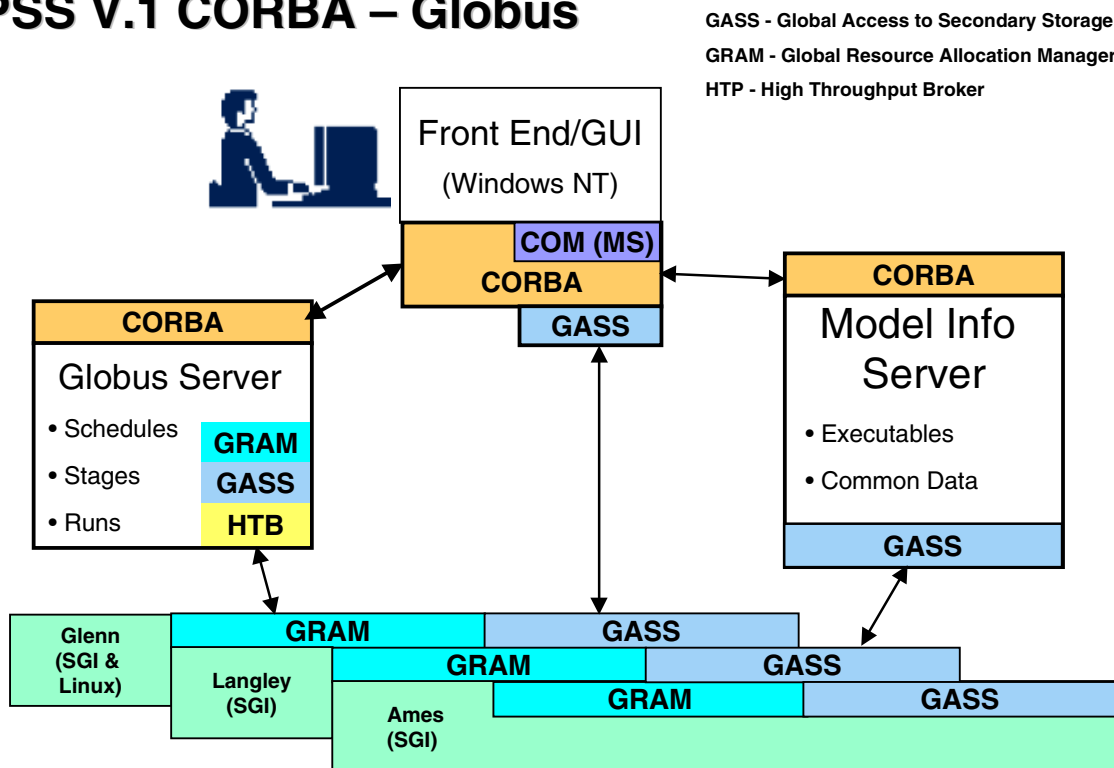
NPSS Rockets Modeling

- Completed a "simplified" RL10A-3-3A model running in NPSS

    - Capable of simulating transient throttling operations (though not start and shutdown)

    - Model is suitable for demo and training purposes (10/6-7)

    - Because we are using a simplified model of the system, we will not be able to benchmark the NPSS results against ROCETS output in 10/99

    - Plan to have benchmark model ready by 1/00

    - Zooming implemented with J. Veres PUMPA code to mirror HTO300 work

RL10 Model Schematic
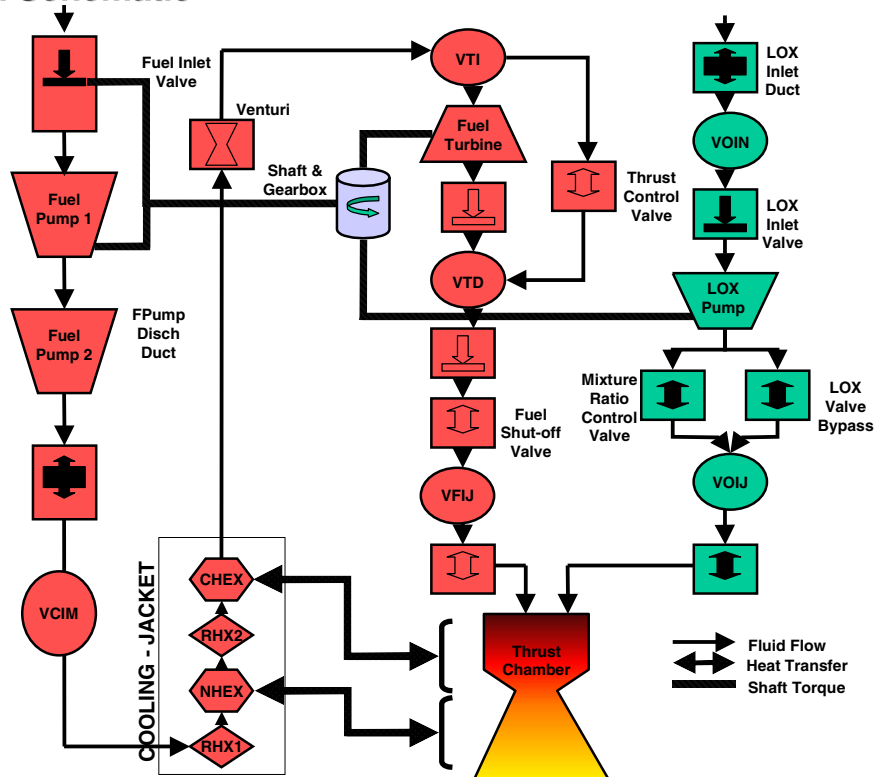
Legend of Symbols in RL10 Model Schematic

Pump

Turbine

Inertial Fluid Flow (flow set by solver, flow derivative calc, reversible flow)

Incompressible Fluid Flow (flow calc, reversible flow)

Incompressible Fluid Flow (discharge P calc, reversible)

Compressible Fluid Flow (flow calc, reversible)

Compressible Fluid Flow (discharge P calc, reversible)

Variable Density Fluid Flow (explicitly integrated flow calc)

Venturi (calibrated to RL10 specs).

Volume Dynamics (for ducts, manifolds, and other adjacent components)

Heat Exchanger (heat transfer, fluid volume and metal temperature dynamics)

Shaft dynamics

NPSS V1.0 Current Status

- Reviewing results of customer evaluation and GE validation activities
  - Reprioritizing as needed
  - Addressing change requests generated by customer feedback
- Working remaining requirements, defects, and enhancements for full release of NPSS Version 1
- Providing NPSS training this week (two 2-day sessions)
  - Using NPSS to Model Air-Breathing Jet Engines
  - Using NPSS to Model Rocket Engines
- Completed gcc port which enables NT, Linux and more
- NPSS Version 2 requirements definition includes dynamics, higher fidelity and multidisciplinary analysis capabilities

NPSS Developement

Date	Version	Engine Models*
7/97	Beta, 0D Cycle S.S.	HSR, Turbojet
8/98	NCP, 0D Cycle+Transients	HSR, Turbojet, Turbofan
7/99	NPSS Increment V1, Customer Deck, Dynamic Link Library	HSR, Tjet, Tfan, EEE, PDE, PSAO Models, GE Validation Model
11/99	NPSS NT, COM-CORBA-GLOBUS	Turbojet, Turbofan
3/00	NP˚ SS V1, 1D/2D Zooming (HTO300), Rockets, 1D Rocket Zooming (PUMPA)	RL10

NPSS Architecture

Objective:

To develop and evolve an Architecture Definition for the NPSS Environment.

Approach:

Assemble a team of Industry and NASA personnel to put forth an Architecture, Implementation Schedule and series of prototypes for validating subject architecture.
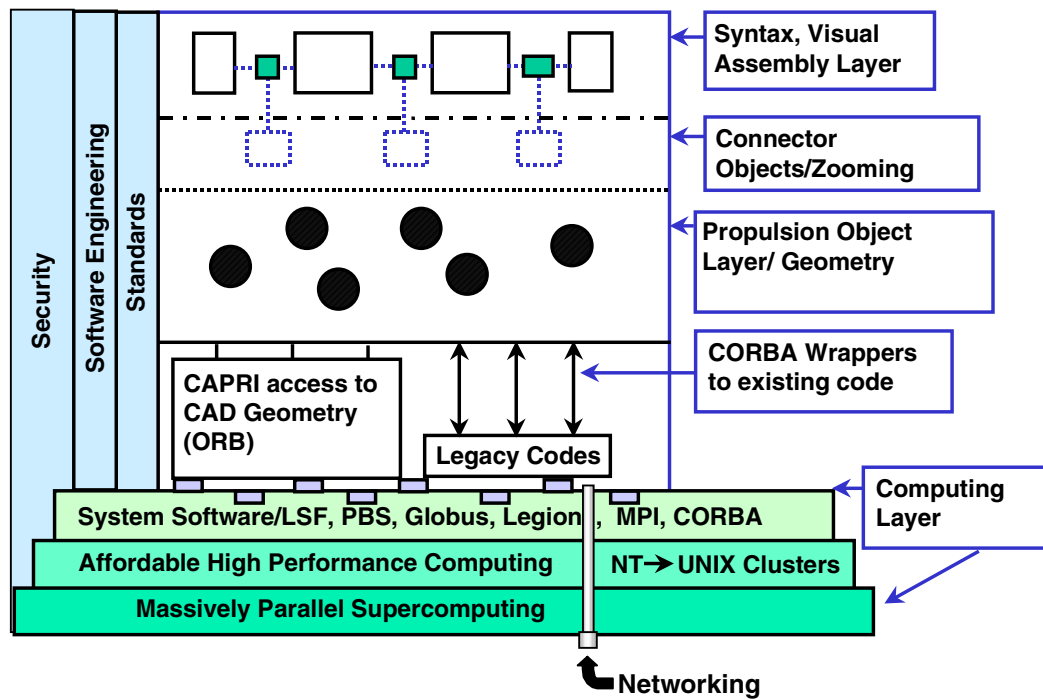
Accomplishments:

Propulsion and Geometry teams were formed to focus requirements. OMG is gaining acceptance of CAPRI. CAPRI API's exist for UG, ProE, CATIA, IDEAS. 1D Zoomed element simulation completed.

Plans:

FY99 & 00 Focus on Propulsion Objects, Zooming and Geometry.

- Adopt the NCP input syntax;
- Adopt CAPRI as the Geometry interface, review progress with UGWAVE;
- Collect the best of VCE, CGNS, BASE IT Object definition to support zooming.
- Update the NPSS Architecture document.

NPSS Object Oriented OPEN Architecture

Security

Software Engineering

Standards

→ Syntax, Visual Assembly Layer

→ Connector Objects/Zooming

→ Propulsion Object Layer/ Geometry

CAPRI access to CAD Geometry (ORB)

Legacy Codes

→ CORBA Wrappers to existing code

System Software/LSF, PBS, Globus, Legion , MPI, CORBA

→ Computing Layer

Affordable High Performance Computing

NT→UNIX Clusters

Massively Parallel Supercomputing

↰Networking

NPSS Architecture:

- **Visual Assembly Layer**
  - Syntax, Visual

- Propulsion, Geometry Layer

- Computing Interface Layer
  - CORBA, Security, Object DB
  - GLOBUS

Visual Assembly
Script Based Syntax

- **NPSS command line based**
  - npss [-v] [-debug] [-I *dirname*] [-corba] [-i] [-log] file1 file2

- **C++ syntax** for element creation, sequence, viewing, CORBA

  Model BWB {
  Element FlightConditions AMB0 {. . .}
  Element Inlet Inlet {. . .}

  linkPorts ("FlightConditions.Outlet", "INLET.F1_I", "FL0");

- **Programming constructs**, declare new variables, comments, If-then-else, do while's, arithmetic functions: *, /, +, -, exponentiation, logicals, >, <, =,....

Visual Assembly
Visual Based Syntax Process Tasks

- Customer Feedback   3/1/99
  - Review NCP Version 1 Usability Feedback
  - Create User Surveys
  - Visit Customer Sites for User Studies
  - Distribute and complete surveys
- Analysis   7/2/99
  - Study the software requirements previously specified for the VBS
  - User Profiles, Current and anticipated task analyses
  - Use Case Scenarios, Usability goals
  - Software and hardware compatibility requirements
- Design   In Progress
  - Storyboards, VBS-NPSS API Definition
  - Low-Fi Prototype, Documentation Online

Visual Based Syntax Analysis Tasks

Basic analysis tasks that should be supported by the VBS are:

1. Model Creation/Modification
2. Steady-State Performance Analysis (Design/Off-Design)
3. Data Reduction Analysis
4. Transient Analysis
5. Customer Deck Generation/Maintenance/Execution
6. Control Design Support (State-Variable Model)
7. Phase II, III requirements

All of these basic tasks have some functions in common, which are:

8. Case Management, plotting, interactive debug

NPSS Architecture:

- Visual Assembly Layer

- **Propulsion, Geometry Layer**

- Computing Interface Layer
  - CORBA, Security, Object DB
  - GLOBUS

Propulsion Layer

Objective:

Define the engine system objects and supporting infrastructure required by NPSS to conduct design/analysis of Engine Systems and:

- Component Numerical Zooming
- Multidisciplinary Coupling

Approach:

Adhere to the object oriented design philosophy while building off of the NPSS V1.0 object layer and thereby growing the Object Layer to encompass Zooming and MD.

Propulsion Layer
NPSS 0D Objects

User's conceptual view of the physical components of the engine model can be mapped directly onto the object class hierarchy. All simulations are created from a collection of building block classes used to represent engine components.

- Elements
  - Primary building blocks connected together via Ports
- Sub-Elements
  - Interchangeable secondary building blocks that plug into Elements and other Sub-Elements
- Flow Stations
  - Responsible for thermodynamic and continuity calculations (JANAF, THERM, GASTAB)
- Ports
  - Used to connect Elements together, Four types (Mechanical, Fluid, Fuel, Thermal)
  - Directional in nature (outputs connect to inputs)
- Tables
  - Organized set of numbers that relate n-dimensional inputs to a specific output
  - Supports linear and second or third order LaGrange interpolation
  - Supports fixed value end-points or extrapolation (linear/2nd/3rd order LaGrange)

Propulsion Layer
Object Based Turbojet Assembly
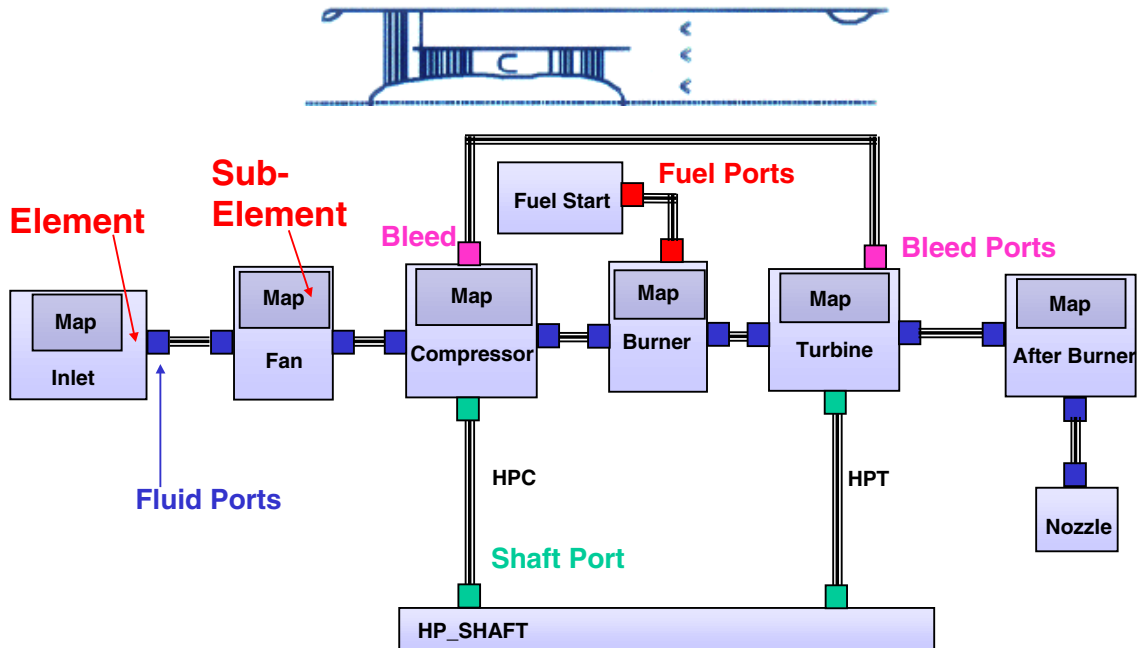
Propulsion Layer
0D - 3D

Objective:

- Develop a strategy and implementation plan for the integration of mixed fidelity and multidisciplinary models into the NPSS framework.

Approach:

- Analyze existing integration efforts MDICE, Low Pressure Subsystem, LAPIN, PRICE, NPSS External Element, CGNS.
- Analyze code integration issues and potential solutions.
- Develop a needs list of resources and skill sets required to implement strategy. Identify key functional requirements for component data exchange.

Status:

- Draft paper is being developed as initial roadmap for growing the NPSS Version 1.0 object layer to support mixed fidelity and MD simulations. (10/1/99). Subject of next architecture meeting November '99.

NASA/Glenn Application Software

Inlet/ Ducts	Fan	Compr	Turbine	Combustor	Features	Fidelity
					▭ NASA/Glenn code	
NPSS V1.0/Wate					Thermodynamic, Engine System, Weight, Controls, approximate flowpath	0 - Dimensional
LAPIN	MODFAN	CMPGEN	TURBAN		Off-design, scaled map, flowpath, blades	1 - Dimensional
	CDP, UDO300, SANZ				Detailed design, blades & flowpath	2 - Dimensional
ENG10/20					Engine system, axis-symmetric aero	2 - Dimensional
NPARC	APNASA, ADPAC, HAH3D, RVC3D			NCC	Aero, single/multi-blade row, viscous, combustor chemistry	3 - Dimensional
NASTRAN, PATRAN, MARC, ANSYS					Structural, thermal	3 - Dimensional
NESSUS, NESTEM,CSTEM,IPACS					Probabilistic, Thermal, Structures	3 - Dimensional
NPARC	MSU-TURBO, TURBO-AE, RVC3D			NCC	Aero, emissions, noise, transients, structural dynamics, unsteady, multi-blade row, aeroelastic	3 - Dimensional

Geometry Layer

Objective:

- Define and provide a common means of accessing geometry from the major commercial CAD packages for use within NPSS engine simulations.

Approach:

- Maintain awareness of Commercial CAD directions (UGWAVE),
- Develop an API leading to an object layer that generalizes the CAD specific access and is minimally intrusive to existing codes so adoption is not fought by the code developers. Where necessary, create excessive anxiety on the CAD vendors to move them to integrate the API through participation in the Object Management Group (OMG).

Geometry Layer

CAPRI - Computational **A**nalysis **PR**ogramming **I**nterface

A Geometry based library providing common access to vendor specific CAD files (ProE, Unigraphics, CATIA, IDEAS).

Position: CAPRI will be the Geometry Interface for NPSS

AERO   STRUCTURES   Heat Transfer

Gridding/Visualization/Solving

CAPRI			
Unigraphics	Pro E	CATIA	. . . .

CAD: Geometry Kernel/Database
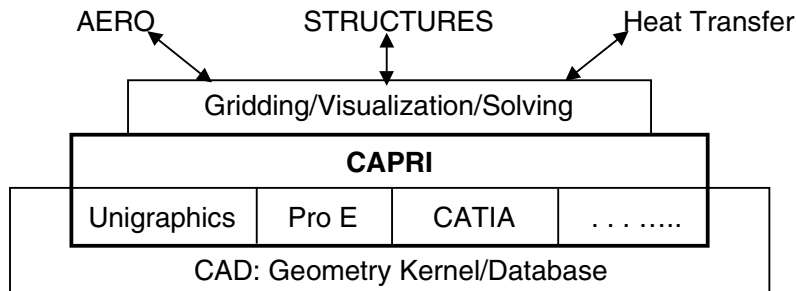
FY99 - Presented CAPRI to OMG for adoption into Specification
FY00 - Corba'fy CAPRI creating Geometry Server

Geometry Layer

Status:

- CAPRI API's exist for Unigraphics, ProE, CATIA, IDEAS.

- NASA LaRC will demo their use of CAPRI within Gridex.

- NASA GRC using CAPRI on Trailblazer concept.

- NASA ARC/Mike Aftosmis, Automatic Generation of CFD-Ready Surface Triangulations from CAD Geometry, AIAA 99-0776.

- UGWAVE from Unigraphics status later in presentation.

- Architecture Team formed to continue development and testing.

- Developing technology roadmap this week.

Geometry Layer

Status:

- CAPRI - Object Management Group (OMG)
  - CAD to CAE meeting in Detroit hosted by Ford with Daimler Chrysler, Unigraphics, SDRC.
    - Build business case with customer, CAD vendors were receptive if demand exists. (Tried of writing interfaces)
    - Integrate CORBA - CAPRI into a PDM.
    - Build prototype to answer performance questions, network load.
  - RFP started at San Jose 8/25, Draft RFP available for Boston 11/15/99.
  - RFP requirements will reside in NPSS SRS (Geometry and Topology requirements).
  - Update report at next Architecture meeting 11/2.

CAPRI Trailblazer Integration Using ProE at GRC
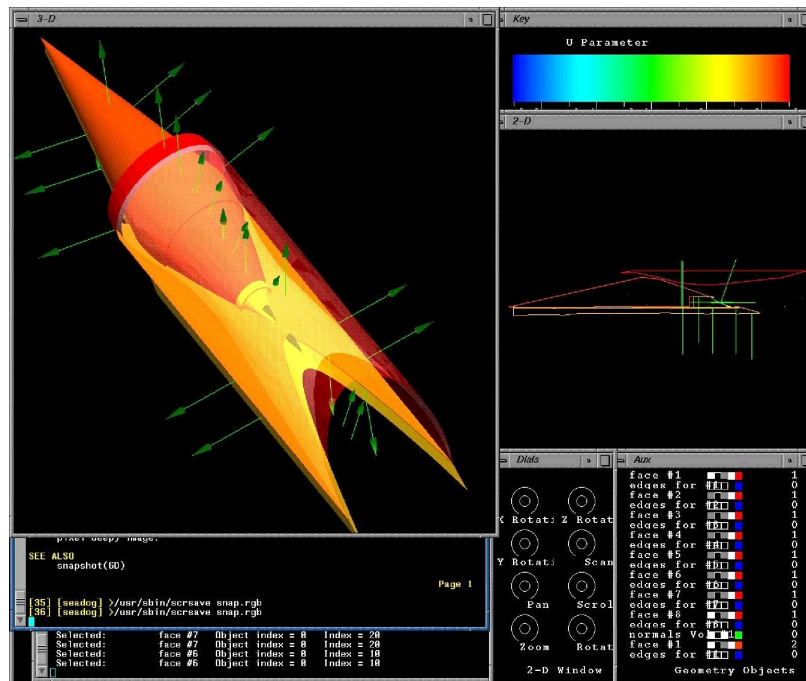
Geometry Layer
NASA LaRC's use of CAPRI within Gridex
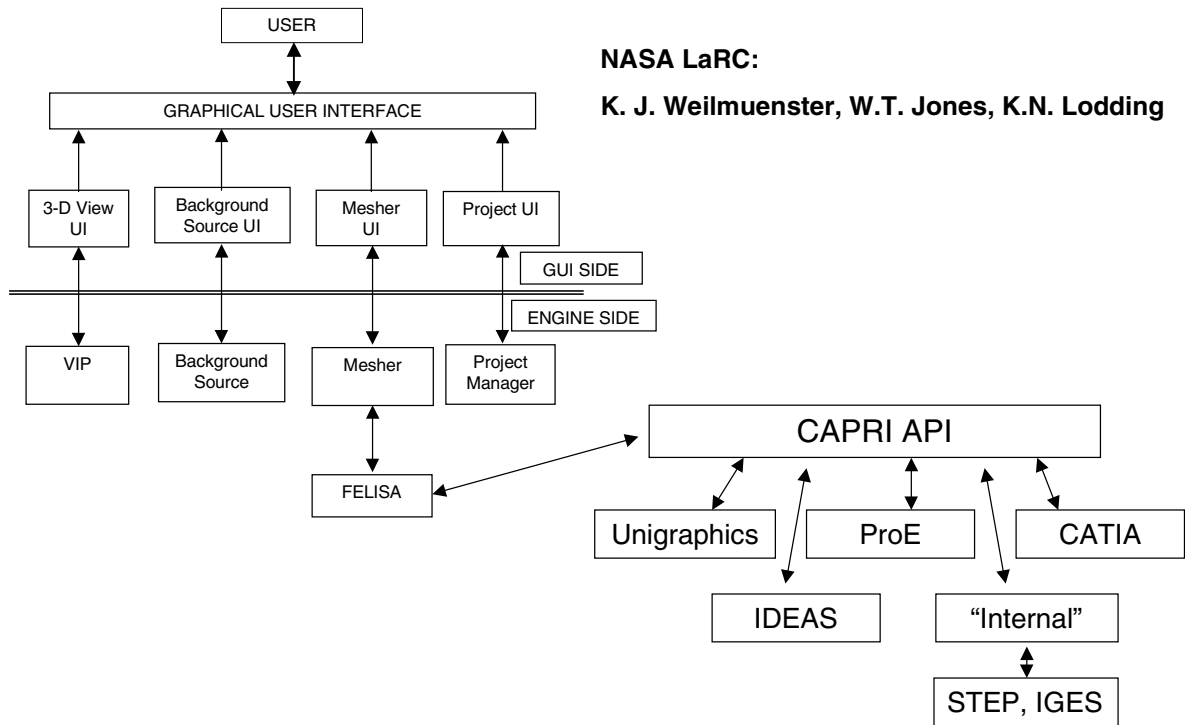
```
                    ┌──────────┐
                    │   USER   │
                    └──────────┘
                         ↕
        ┌─────────────────────────────────────┐
        │    GRAPHICAL USER INTERFACE          │
        └─────────────────────────────────────┘
           ↕          ↕          ↕         ↕
     ┌─────────┐ ┌──────────┐ ┌────────┐ ┌──────────┐
     │ 3-D View│ │Background│ │ Mesher │ │Project UI│
     │   UI    │ │Source UI │ │   UI   │ │          │
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                                          │ENGINE SIDE │
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       ↕           ↕           ↕           ↕
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   │  VIP  │ │Background │ │ Mesher │ │ Project  │
   │       │ │ Source    │ │        │ │ Manager  │
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```

NASA LaRC:

K. J. Weilmuenster, W.T. Jones, K.N. Lodding

CAPRI API
Unigraphics   ProE   CATIA
IDEAS   "Internal"
STEP, IGES

NPSS Architecture:

Visual Assembly Layer

Propulsion, Geometry Layer

Computing Interface Layer

CORBA, Security, Object DB

GLOBUS

Computing Interface Layer

CORBA, Security, Object DB

– IONA is baseline for NPSS;

– Wrapping HTO300, complete by 12/1/99.

– CORBA Developer's kit to aid in NPSS integration.

– Evaluation of CORBA Security: Information Encryption Prototype (IEP)

– Finished evaluation of Objectstore using LAPIN

IPG/GLOBUS

– Evaluated five Public ORB's, choosing MICO for IPG

– Demo at SC'99: Launch 100's of NPSS jobs from Excel-COM-CORBA-IPG/Globus (HTO300 if ready)

– NPARC simulation on IPG/Globus

Globus

The PSE layer provides the scientist's / engineer's interface to Grid services. It is an application domain-specific collection of tools (e.g. simulations, databases, instruments), and a "workbench" environment that makes it easy to use those tools and to collaborate with others working on the same problem.

Applications, e.g. simulations, sit below the PSE and use middleware services.

The middleware layer provides different styles of service interfaces for application developers to access the basic Grid services.

Grid services are "standard" interfaces for the functions needed to build and manage distibuted applications of all sorts.

Most "resources" are "local" and will have their own resource managers and use policies. It is the use mechanisms and interfaces for the local resources that the Grid common services are intended to homogenize.
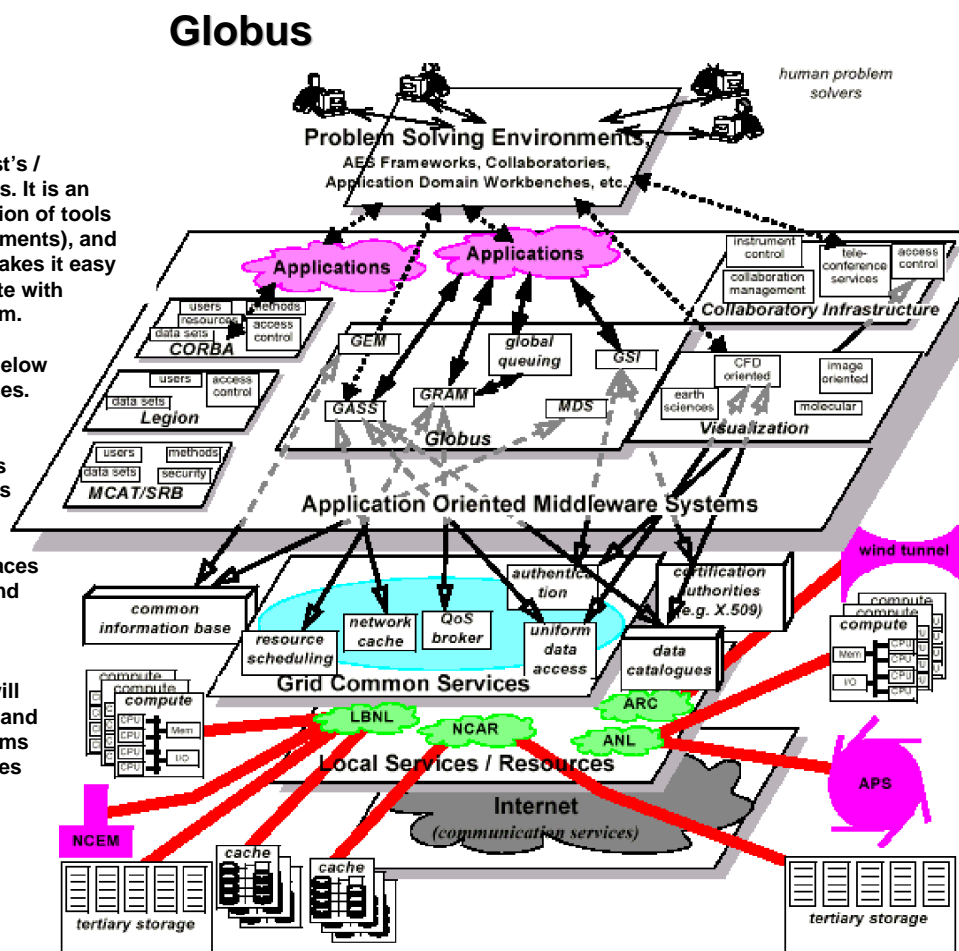
Computing Interface Layer
Database Summary

- Overall, the C++ Object Oriented Database (PsePro) provided excellent performance at a slight increase in programming difficulty. The C++ Simulation Object had to be created using overloaded new operators and this reduced the flexibility of the objects. It was also slightly more complex to create the basic C++ objects with a large number of arrays.

- The Java version of the OODB was quite simple to program and provided reasonable performance. It was, in general, 3 to 10 times slower that the C++ database.

- SQL Server timings were significantly slower and required approximately 1 week's programming time for an experienced programmer. It is likely that we could significantly improve the performance of the SQL Server tests by changing the database to object model design. Query performance of SQL Server was approximately 30 times slower that PsePro for C++

- These tests are not definitive and may be further refined.

Information Encryption Prototype (IEP) Status

- Interim demonstration of the IIP was held on June 2nd on the HPCC ALR NT and Solaris platforms

    – IIP first capability demonstrated a typical performance benchmark using:

        - Data types (byte, integer, short, float, double, char, and String)

        - Data transfer method/structure (individually, array, and vector)

        - All eight RSA encryption options were displayed via GUI, select encrypted and unencrypted tests were performed

    – IIP second capability demonstrated an application specific performance test using large (20KB) Lapin simulation objects transferred as pass-by-value (vs. standard object reference).

Information Encryption Prototype (IEP) Status

NT ALR 1 and NT ALR 2 Networked Batch Test "All" Data Types and "All" Data Structures
Baseline vs. RSA Encryptions
1KB
April 21, 1999
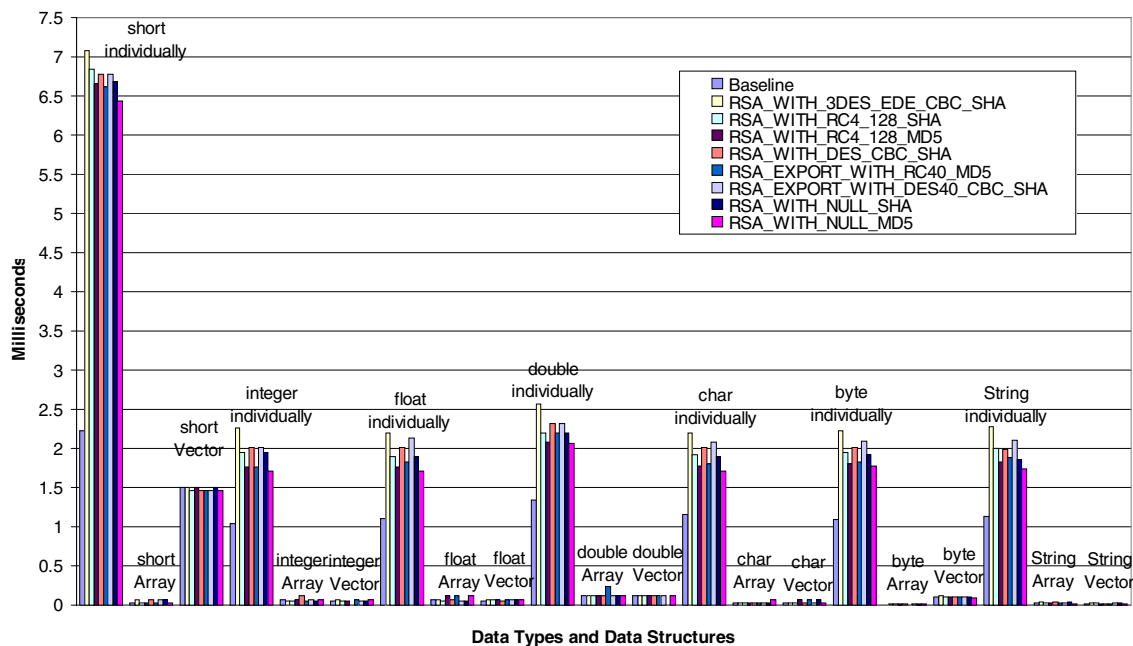
Computer Interface Layer

- Objectstore Database plus more

www.grc.nasa.gov/WWW/IT_BASE_Research/

- Information Encryption Prototype:

www.lerc.nasa.gov/WWW/IEP/

- IPG/Globus

www.globus.org

Globus is a joint project of ISI, Argonne National Laboratory (ANL), and the Aerospace Corporation, and is a focus of research at both NPACI and NCSA. Led by Kesselman and Ian Foster of ANL and the University of Chicago, Globus develops fundamental infrastructure to enable distributed high-performance computing.

New Initiatives

- Sensitivity Analysis/Optimization Layer 9/00
    - Define strategy and implement NPSS V1, Geometry and Propulsion Layers, High fidelity Structures and Aero codes into NESSUS or appropriate derivative.

- Rocket Model
    - RL10 model built with interpreted elements by 1/1/00.
    - Training on NPSS Rocket capability 10/6-7.
    - Reuse existing NPSS Aero infrastructure, add CEC integration, NIST Lib.
    - Working with Space Transportation Division planning process.

- Safety
    - Contribute engine simulation to modeling Global Airspace.

Semantic Analysis of a Scientific Code

- Problem: P = (E - RHO*(U*U + V*V))*(GAM-1)

  What formula is this? Is it correct?

- Semantic Analysis: An experiment in scientific code automated error detection and code explanation.

- Semantic Analysis = Pattern Matching + Physical/Math fomulae List

- Preliminary results are encouraging:

  25% Recognition in two large, blind test cases (85K lines).
  Recognition will improve with time.

FY00 Goals for NPSS

- Continue to progress on Zooming, MD Coupling

- Address overall NPSS requirements: cycle deck, dynamics, high fidelity and multi-disciplines

- Continue to enhance usability: text based syntax, interactive mode, visual based syntax, and user documentation

- Continue to address basic functionality needs mandatory for partners to adopt NPSS

- Continue to extend NPSS rockets capabilities

- Grow the CORBA Wrapping toolkits (Structures)

- Integrate into an NPSS compliant Optimization framework

Summary

NPSS V 1.0:

- July Increment on time, Full V1.0 proceeding on schedule

- NPSS Phase I team Evaluating July Increment

- Applying the NPSS design to Rockets, Safety

NPSS Architecture:

- Visual Assembly layer is moving beyond syntax

- Propulsion Layer will grow from NPSS V1. Objects

- Geometry Layer maturing, Initiate MD in Propulsion Layer

- Zooming tasks to focus on 0D-3D-3D-0D simulation

Engineering Applications

Austin Evans, Joseph Veres, and Karl Owen
NASA Glenn Research Center
Cleveland, Ohio

Engineering Applications & Advanced Propulsion Cycles

- NPSS Version 1
- Dynamic Engine Modeling
- 3-Subsystems/System

High Performance, Affordable Computing

Simulation Environment

Component Integration

MD Coupling

Zooming

- Modular Architecture
  - National Cycle Program
- Toolkits
  - SSCD
  - CM Manager
  - CAPRI
  - MDOW
- Library/Utilities
  - NURBS
  - PEV
  - Data Standards

- 3-D Combustor w/ Design, Pre, Post Proc.
- Spectrum /MultiPhysics
- Secondary Flow

- Inlet/Engine Coupling
- UGWAVE
- 0-D Core 3-D LP Subsystem
- 3-D Combustor/ 3-D Engine

- High-Speed Networks
- Code Parallelization
- Load Sharing Facility
- P6 Cluster
- O2K Metacenter

Roadmap for NPSS Overnight Simulations

| 97 | 98 | 99 | 00 | 01 | 05 | 10 |

1-D Engine (National Cycle Program)

Axisymmetric Engine

3-D Engine Steady-State Aerodynamic

3-D Engine Steady-State Multidisciplinary

3-D Engine Dynamic Multidisciplinary

3-D Low Pressure Subsystem (ADPAC)/ 1–D HP Core

3-D Engine (APNASA)/ 2–D Combustor

3-D Reacting Flow (National Combustor Code)

UG/WAVE Common Geometry

3–D High Pressure Compressor (Design Point) (APNASA)

Multistage Compressor Map

Integrated Propulsion/Airframe Simulation

Standards and Zooming

Standards

Objective:
Clearly define and implement within NPSS standard ways of handling data, interacting with users and performing engineering analysis.

Approach:
NPSS will work closely with National and International standards organizations to implement existing standards within NPSS, expand standards as required and develop new standards when necessary.

Point of Contact:

Austin Evans   (216) 433-8313   (Engineering Standards)

Greg Follen   (216) 433-5193   (Software Standards)

Standards

Goal	Status	% Goal	FY 00 Plan
Implement generation Cycle Stds.	Implement AS681 ARP4868, ARP4191 into NPSS	75	Demonstrate of AS customer deck
Implement implementation MD & Topology Stds.	Support Inclusion of GGA into STEP Part 42 & Completion of AP209 Phase 2 (1 to 4 years)	80	Define into Architecture adopt CAPRI.
Implement Commercial Implementation Software Stds. Member-	C++ Rules and Common Desk Top Environment Implemented CORBA adopted	80	Continue Upgrade OMG ship. RFP due 11/99.
Implement Internal Standards Software Stds.	5 Internal Standards Documents Complete	95	Yearly Review Add Security

Variable Complexity Analysis (Zooming)

Objective:

Clearly define and implement within NPSS standard ways of performing variable complexity analysis.

Approach:

Working closely with industry:

– Identify the types of Zooming to be implemented in NPSS
– Develop uses cases for the categories of Zooming
– Develop prototype Zooming applications
– Implement Zooming hooks and tools into NPSS

Point of Contact:

Austin Evans   (216) 433-8313

Phase I NPSS Deliverables 0 And 1 D
Preliminary and Conceptual Design Systems

Phase II NPSS Deliverables 2 D and Quasi-3 D Engine Systems Operability

Phase III NPSS Deliverables 3 D Detailed Design & Analysis System

Variable Complexity Analysis (Zooming)

Goal	Status	% Goal	FY 00 Plan
Identify Classes of Zooming	4 Types of Zooming Identified	75	Further define classes of zooming
Define classes of geometry zooming	UG Wave evaluated Define component templates	35	Continue and define geo. Zooming control strucutre
Develop Prototype Zooming Applications	3 Prototype Applications ongoing: Full turbofan simulation ongoing	80	Complete development for 3 Prototypes
Implement Zooming into NPSS	Test NPSS V1 Zooming Hooks NCP-1D compressor	70	Test NPSS V1 Zooming Hooks NCP- HTO300, ADPAC

Engine Systems and Subsystems

Joseph Veres
NASA Glenn Research Center
Cleveland, Ohio

Roadmap for NPSS Overnight Simulations

97   98   99   00   01   05   10

1-D Engine (National Cycle Program)

Axisymmetric Engine

3-D Engine Steady-State Aerodynamic

3-D Engine Steady-State Multidisciplinary

3-D Engine Dynamic Multidisciplinary

3-D Low Pressure Subsystem (ADPAC)/ 1–D HP Core

3-D Engine (APNASA)/ 2–D Combustor

3-D Reacting Flow (National Combustor Code)

UG/WAVE Common Geometry

Multistage Compressor Map

3–D High Pressure Compressor *(Design Point)* (APNASA)

Integrated Propulsion/Airframe Simulation

Multidisciplinary Design Optimization Using UG / WAVE

Objective
To develop an associative control framework in a Unigraphics CAD environment enabling multidisciplinary design of propulsion systems

Approach
To apply WAVE (What-if Alternative Valve Engineering) CAD design tool to control key design variables to create a complete gas turbine engine in a Unigraphics environment

Benefits
• The creation of a common geometry will encourage level concurrent engineering
• Supports concept to detailed design engineering and rapid optimization
• Standardization and automation of design practice and serves to capture the "corporate memory"
• Contract with G.E. Aircraft Engines (GEAE) NAS3-98004, Task Order #2

Common Geometry
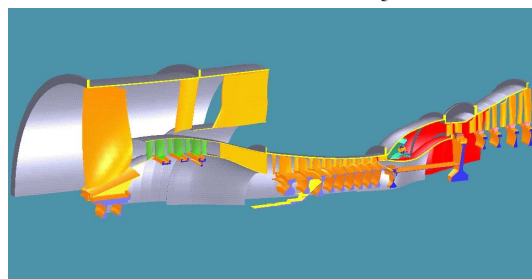
Point of Contact
Joseph Veres
tel.: (216) 433-2436
fax: (216) 433-5188
e-mail: jveres@grc.nasa.gov

NASA/TM—2000-209795   49

Multidisciplinary Design Optimization
Using UG / WAVE

Accomplishments (FY99):

1. The TEST Task Order contract with GEAE has demonstrated the ability to drive the design of turbofan engines from the system level.

2. Detailed solid model geometry of a high bypass ratio turbofan engine has been created from simple parametric geometry.

3. A complete associative high bypass turbofan master model has been created in the Unigraphics environment.

4. Demonstrated Knowledge Based Engineering (KBE) concepts applied to master model creation and update.

5. A Status Review of this task was held at NASA Glenn Research Center on May 27, 1999.

6. The UG / WAVE control structure, with high bypass ratio turbofan engine, has been delivered to NASA Glenn Research Center in August 1999.

Multidisciplinary Design Optimization
Using UG / WAVE

Fan component design starts with definition of hub and tip flowpath, and blades from cycle and 1-D conceptual design code

Fan blade disk attachment and casing details are generated by DESIGN RULES in UG spreadsheet and assembled in an associative manner

Fan assembly

Multidisciplinary Design Optimization
Using UG / WAVE

Boost compressor design starts with definition of hub and tip flowpath, and blades from cycle and 1-D conceptual design code

Boost compressor blades, disk attachment and casing details are generated by DESIGN RULES in Unigraphics spreadsheet

Geometric zooming

Boost compressor assembly

Multidisciplinary Design Optimization
Using UG / WAVE

High pressure compressor assembly

HP compressor design from definition of hub and tip flowpath, and blades from cycle and conceptual design code

HP compressor blades, disk attachment and casing details are generated by DESIGN RULES in Unigraphics spreadsheet

Multidisciplinary Design Optimization
Using UG / WAVE

Engine components are designed and assembled in an associative manner by the template driven UG / WAVE architecture

Solid model common geometry model of complete high bypass turbofan engine in a CAD environment

Multidisciplinary Design Optimization
Using UG / WAVE

Plans (FY00):

1. Continue development of control structure (TEST TO#2 with GEAE).

2. Creation of generic parts sketches to populate the control structure.

3. Utilize Unigraphics KBE to drive geometry from a rules database.

4. Integration with NPSS (v 1.0) to support the flow of information / data.

5. User interface development in conjunction with the NPSS (v 1.0) design.

6. Training by GE personnel at NASA Glenn Research Center in the use of the UG/WAVE control structure.

Dual-Spool, Multi-Fidelity Engine Model

Objective

Develop a detailed flow simulation of the low pressure subsystem within a gas turbine engine using a simplified core engine model.

Approach

- Apply the ADPAC 3-D Navier-Stokes flow code to the Energy Efficient Engine LP Subsystem consisting of: nacelle, inlet, fan, bypass duct, mixer, LP turbine and nozzle creating a 3-D flow model of LP Subsystem.
- BC's at the core engine inlet and exit will interact with the thermodynamic cycle.
- The simulation runs on parallel on distributed workstations.
- NAS3-27394, Task Order #17.
- Core Engine simulated with NPSS (v1.0).

Impact/Metrics

- Evaluate the interaction effects between the LP subsystem components while considering the boundary conditions at the core engine.
- The LPs model will reduce design/development time by enabling the designer to numerically investigate engine operability.
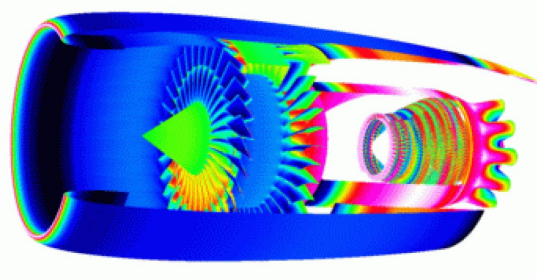
Applications

- All new turbofan engines under development
- Allison AE 3007 Engine
- EEE Turbofan Engine (research testbed).

Point of Contact

Don VanDrei
tel.: (216) 433-9089
fax: (216) 433-5188
e-mail: Donald.E.VanDrei@grc.nasa.gov

Dual-Spool, Multi-Fidelity Engine Model

Accomplishments: (FY99):

1. The mixed fidelity (hybrid) engine model of the EEE engine has been developed at Allison / Rolls-Royce. The Model consists of an ADPAC CFD flow simulation of the low pressure subsystem, and an NPSS (version 1.0) cycle simulation of the core engine.

2. The NPSS (v 1.0) thermodynamic cycle model of the EEE engine is complete, including all component performance maps.

3. The NPSS (v 1.0) thermodynamic cycle model of the AE3007A1 engine is complete and has been validated through comparison with the Allison / RR TERMAP system analysis.

4. The closely coupled HP / LP turbine, having a short transition region, has been simulated with ADPAC on a Silicon Graphics ORIGIN 2000 system employing 3.4 million grid point mesh.

5. A time-dependent angle-of-attack 3-D full rotation model for the EEE fan is complete.

6. A CORBA wrapper for ADPAC has been completed.

7. A driven mode version of NPSS (v 1.0) to be used in the mixed fidelity model has been completed.

8. A C++ executive control application has been created to assist in the development of a more direct coupling procedure.

Multi-Fidelity Engine Model

Current Computational Model
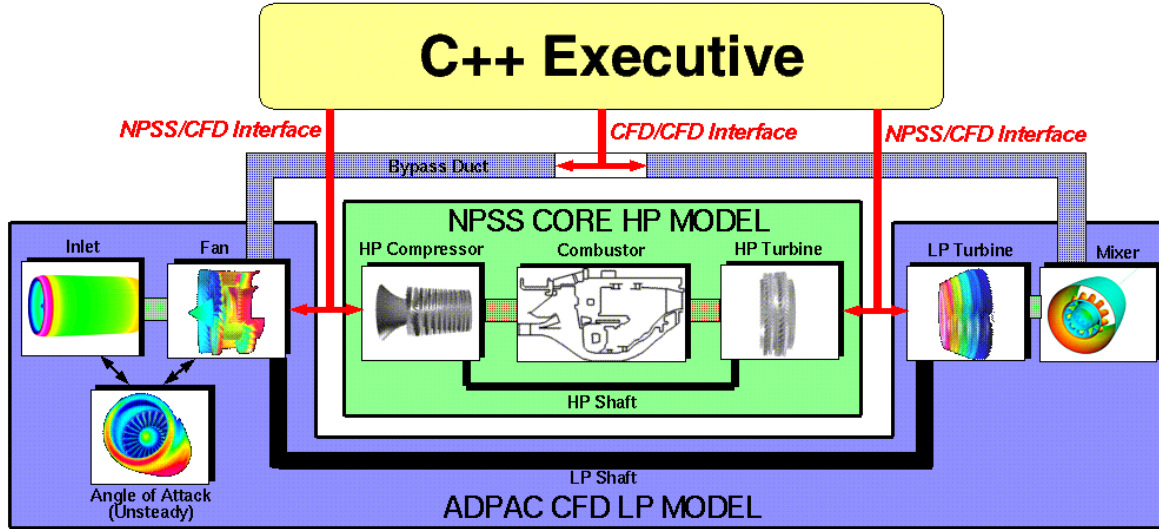
CFD-based shaft power balance:
20 processors, 5 RPM adjustments, 14 hours

Multi-Fidelity Engine Model

Modular Computational Model
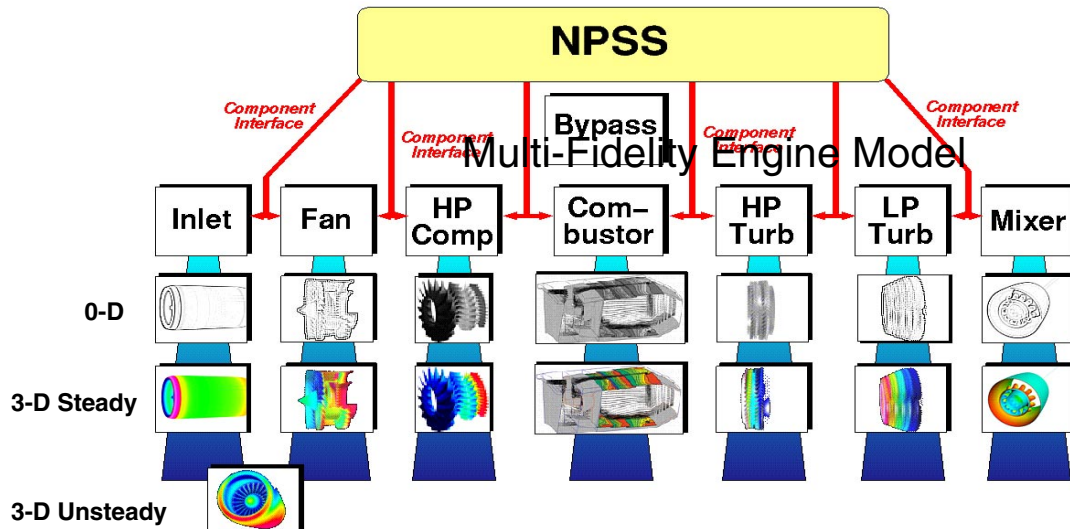
Dual-Spool, Multi-Fidelity Engine Model

Plans: (FY00):

1. To develop a "modular" CFD simulation strategy for whole engine performance prediction.

2. Dual spool analysis of the EEE and the AE3007 engines with NPSS (v 1.0) / ADPAC simulation.

3. Incorporate the 3-D angle of attack analysis into the NPSS / CFD framework to provide engine incidence analysis with dual spool torque balance, using the modular CFD engine simulation strategy.

4. Optimization of parallel performance of engine model, particularly with respect to the problem of load balancing for whole engine simulations involving mesh blocks with widely varying sizes. This will be performed in collaboration with Indiana University Purdue University at Indianapolis (IUPUI).

5. Execute, verify and validate coupled ADPAC / NPSS (v 1.0) simulation of dual spool engine.

6. Initiate integration of mixed-fidelity ADPAC / NPSS flow model with an flow simulation over an airframe and wing.

Detailed Flow Simulation of Modern Turbofan Engine

Objective
Develop a detailed flow model of a full turbofan engine that runs on parallel workstation clusters overnight. The model will simulate the 3-D flow in the primary flowpath including the flow and chemistry in the combustor.

Approach
- The 3-D flow analysis models the GE90 turbofan engine using APNASA (NASA's average passage flow code).
- The project leverages form current efforts between NASA and GE in developing the APNASA flow code and workstation clustering technology.
- Contract with GEAE NAS3-98004 Task Order #9
- The National Combustion Code (NCC) will be used to simulate the flow and chemistry in the combustor.
- The APNASA and NCC will be coupled together and exchange boundary conditions.
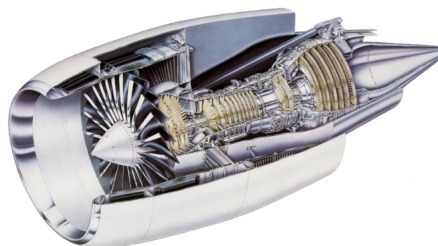
Significance/Metrics
The overnight 3-D flow simulation capability of the primary flow path in a complete engine will enable significant reduction in the design and development time of gas turbine engines.

Point of Contact
Joseph Veres
tel.: (216) 433-2436
fax: (216) 433-5188
e-mail: jveres@grc.nasa.gov

Detailed Flow Simulation of Modern Turbofan Engine

Milestones: **Status:**

1. **Define engine configuration and operating point: Mach 0.25 takeoff, Sea Level** (*complete*)
2. **Cooled fully coupled HP / LP turbine simulation with APNASA** (*complete)*
3. **Full combustor geometry model from compressor exit diffuser to HP turbine** (*complete*)
4. **Establish turbomachinery and combustor inlet and exit BC's: air, fuel flow rates** (*complete*)
5. **Full compression system simulation with fan, booster and HP compressor**
6. **Full turbomachinery using APNASA (torque balance)**
7. **Cold-flow full combustor simulation with NCC** (*complete*)
8. **Redefine engine configuration, operating point BC's** (*complete*)
9. **Re-run HP / LP turbines, re-run full compression system (milestones 2, 5, 6)**
10. **Transfer APNASA (version 5) to NASA Glenn Research Center** (*complete*)
11. **NCC Combustor simulation with heat release** (*complete*)
12. **Demonstrate interface of combustor and turbomachinery simulations**
13. **NCC Combustor simulation with reacting flow**
14. **Core engine model with heat release in combustor**
15. **Core engine model with reacting flow in combustor**
16. **Integrate simulations of turbomachinery and combustor with reacting flow**

Detailed Flow Simulation of Modern Turbofan Engine

Accomplishments: Turbomachinery (FY99):

1. Task Order #9 of the TEST Contract (NAS3-98004) with GEAE has been initiated to create a flow model of a high-bypass ratio turbofan engine with the APNASA flow code. The task is a follow-on to LET contract Task #65.

2. A Contractors Report has been written to summarize the LET contract Task #65 effort: NASA / CR-1999-209410.

3. A Status Review presentation by GEAE was held at NASA Glenn on July 12, 1999, on the TEST T/O #9 effort.

4. A paper titled "Multistage Simulations of the GE90 Turbine" was presented at the 1999 ASME International Gas Turbine and Aeroengine Congress and the International Gas Turbine Institute, in Indianapolis, Indiana. Also reported in NASA/CR–1999-209311, September 1999.

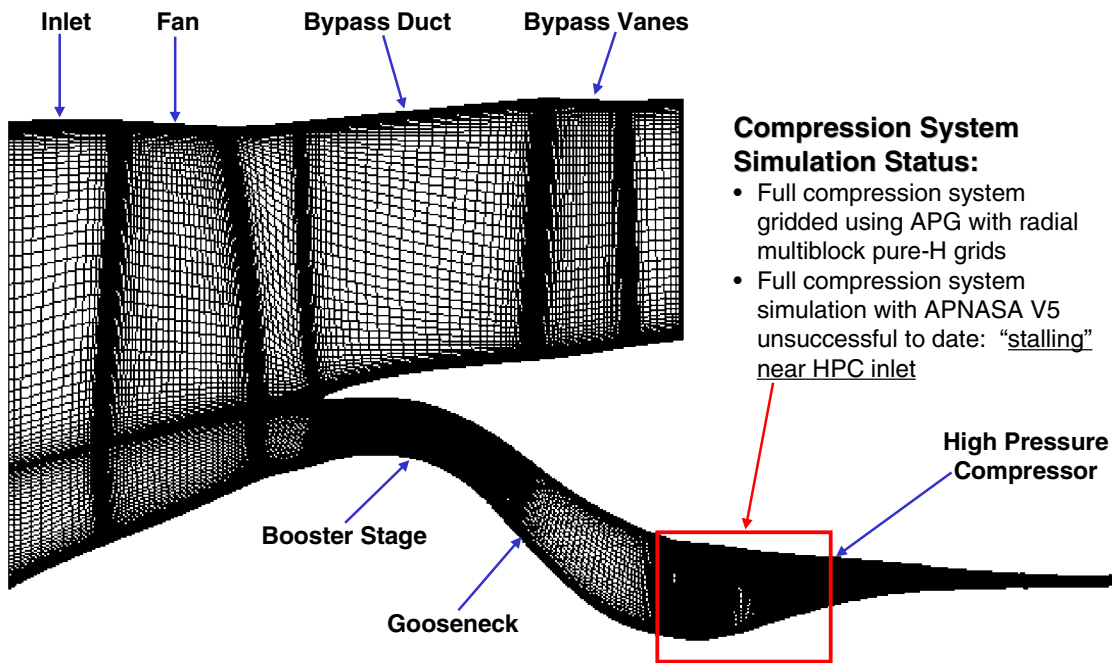## Detailed Flow Simulation of Modern Turbofan Engine
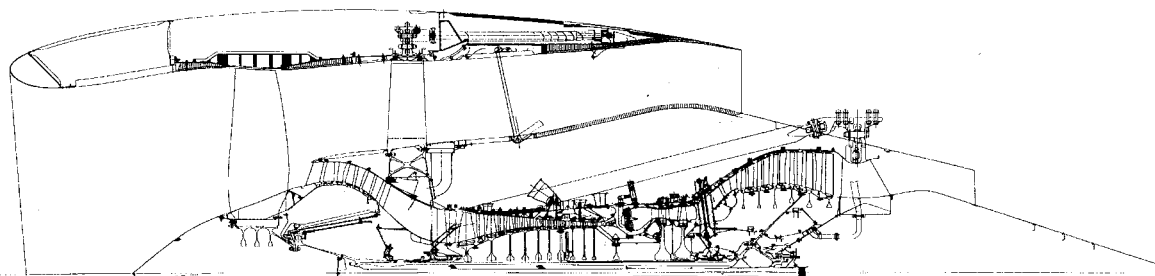
49 blade rows
- fan
- OGV
- 3 stage booster (7 blade rows)
- fan frame strut
- 10 stage high pressure compressor (21 blade rows)
- 2 stage high pressure turbine (4 blade rows)
- turbine mid-frame strut
- 6 stage low pressure turbine (12 blade rows)
- turbine rear frame strut

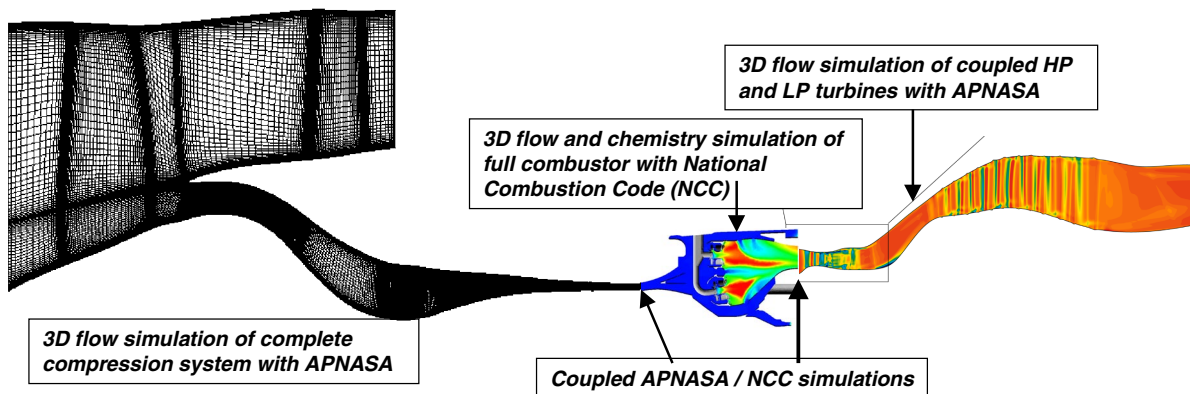## Detailed Flow Simulation of Modern Turbofan Engine

Rigs
- LPT ✓
- HPT ✓
- HPC ✓
- booster ✓

Building Block Approach

✓ = simulations completed

Components:
- fan + OGV + booster S1 ✓
- fan + booster + bypass ✓

System:
- Compression   *In progress*
- Turbine ✓
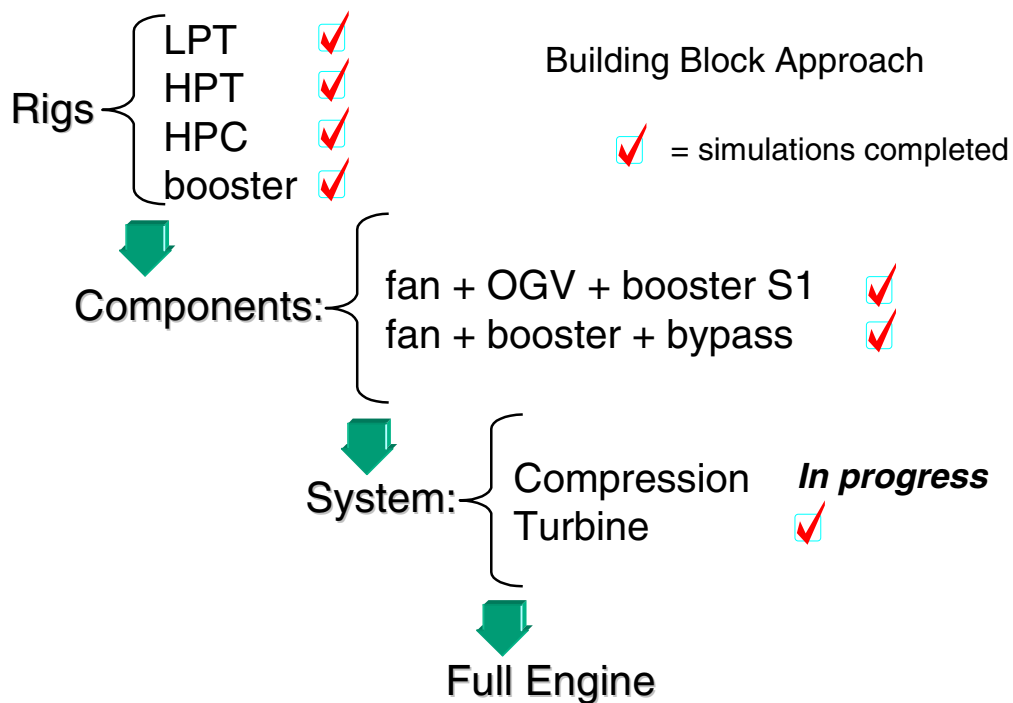
Full Engine

Detailed Flow Simulation of Modern Turbofan Engine

Inlet   **Fan**   **Bypass Duct**   **Bypass Vanes**

Compression System Simulation Status:
- Full compression system gridded using APG with radial multiblock pure-H grids
- Full compression system simulation with APNASA V5 unsuccessful to date: "stalling" near HPC inlet

High Pressure Compressor

Booster Stage

Gooseneck

Detailed Flow Simulation of Modern Turbofan Engine

Plans: Turbomachinery (FY00):

1. Completion of Task Order #9 of the TEST Contract to create a flow model of a high-bypass ratio turbofan engine with the APNASA flow code.

2. Deliver APNASA version 5 the turbomachinery restart files.

3. Publish a Final Report.

4. In-house coupling of the APNASA turbomachinery simulation to the NCC combustor simulation.

3D flow simulation of coupled HP and LP turbines with APNASA

3D flow and chemistry simulation of full combustor with National Combustion Code (NCC)

3D flow simulation of complete compression system with APNASA

Coupled APNASA / NCC simulations

Flow Solver for National Combustion Code (NCC)
Multidisciplinary Combustor Design and Analysis
System with Emissions Modeling

Objective
Develop an integated system of codes for combustor design and analysis to enable a factor of 5 reduction in cost and analysis time.

Approach
- Develop a computational combustion dynamics capability (CCD).
- CORSAIR-CCD is a Navier-Stokes flow solver based on an explicit four-stage Runge-Kutte scheme.
- Unstructured meshes.
- Run on networked workstation clusters.
- The solver can be linked to any CAD system via Patran file system.
- Simulate the flow and chemistry in a modern turbofan engine's combustor - GE90.
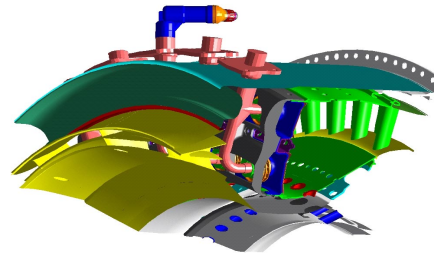
Significance/Metrics
- The National Combustor Code is a systems of codes that will enable the multidisciplinary analysis of the full combustor from compressor exit to turbine inlet.
- The CORSAIR-CCD code is the baseline flow solver module.

Point of Contact
Dr. Nan-Suey Liu
tel.: (216) 433-8722
fax: (216) 433-5802
e-mail: fsliu@grc.nasa.gov

National Combustion Code (NCC) Simulation
of Turbofan Combustor

Accomplishments: (FY99):

1. Sub-component models of the full combustor geometry have been obtained from GEAE consisting of the compressor exit diffuser, swirlers, fuel nozzles, fuel tubes, inner and outer liners, and turbine nozzle vanes.

2. A 3D solid model assembly of the full combustor has been constructed in the Unigraphics environment at NASA Glenn Research Center.

Fuel tubes

Turbine nozzle

Compressor exit diffuser
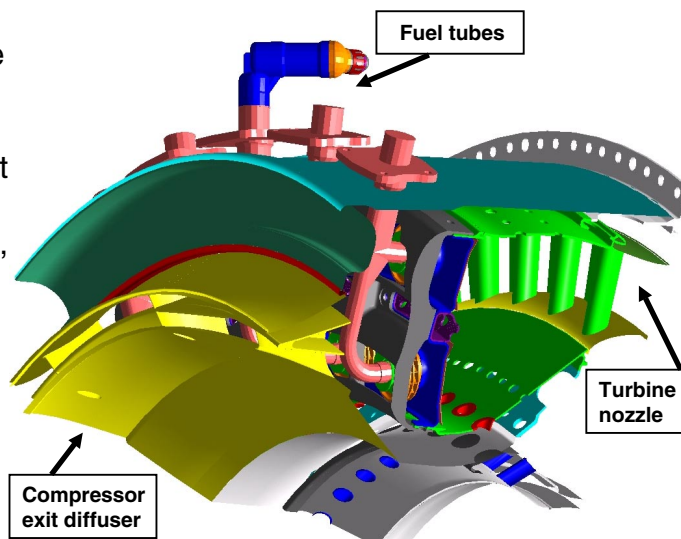
National Combustion Code (NCC) Simulation
of Turbofan Combustor

Accomplishments: (FY99):

3. A "CAD ready" air-solid of the combustor sector was successfully created from the 3D solid model using the Unigraphics CAD package.
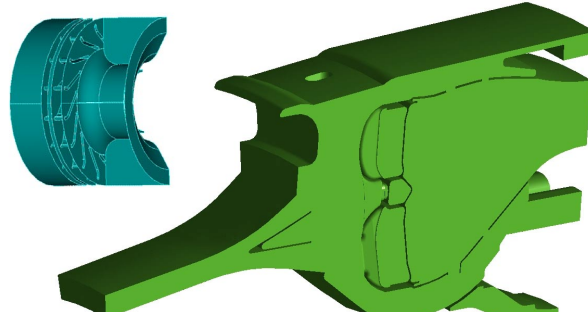
4. A computational mesh for the combustor was generated directly from the Unigraphics CAD file of the air solid.
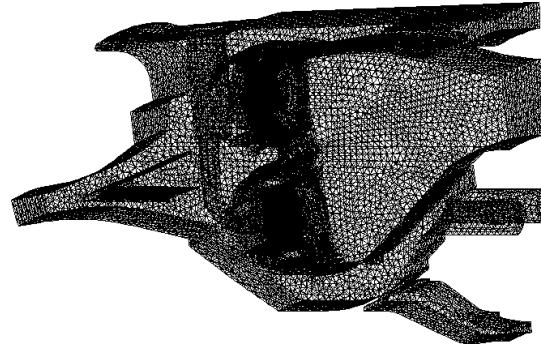
National Combustion Code (NCC) Simulation
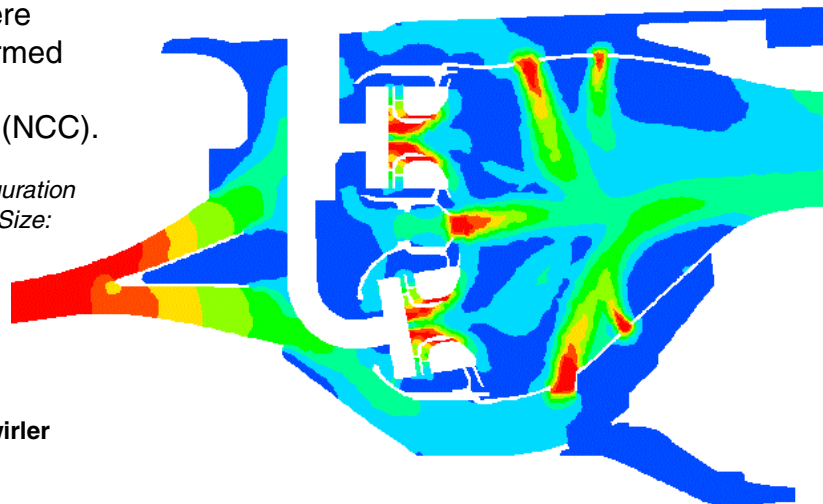## of Turbofan Combustor

Accomplishments: (FY99):

5. Cold-flow combustor simulations using initial coarse meshes were successfully performed using the National Combustion Code (NCC).

Two Fuel Nozzle Configuration Computational Domain Size: 350,000 elements
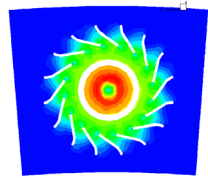
Velocity Magnitude

Swirler

National Combustion Code (NCC) Simulation
of Turbofan Combustor

Accomplishments: (FY99):

6. Hot-flow combustor simulations using initial coarse meshes were successfully performed using the National Combustion Code (NCC).

Two Fuel Nozzle Configuration
Computational Domain
Size: 350,000 elements
15,000 iterations

1-Step Eddy BreakUp
Combustion Model
(fuel + oxygen = products of combustion)
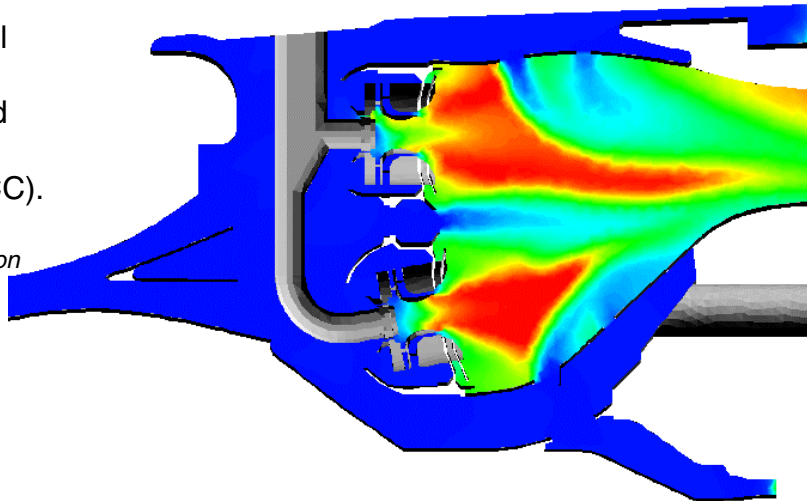
National Combustion Code (NCC) Simulation
of Turbofan Combustor

Isotherms

Isotherms

Temperature

Pressure
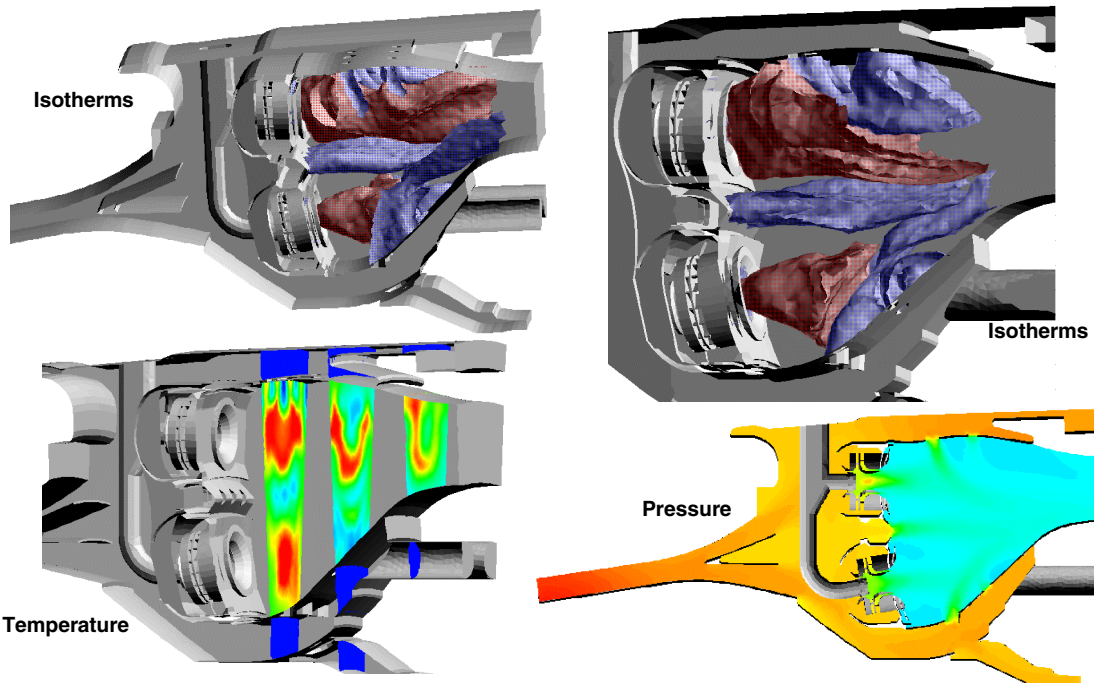
National Combustion Code (NCC) Simulation
of Turbofan Combustor

Plans: (FY00):

1. Demonstrate interface of combustor and turbomachinery simulations.

2. NCC combustor simulation with reacting flow.

3. Integrate simulations of turbomachinery with APNASA and combustor with reacting flow NCC model.

4. Core engine model (APNASA turbomachinery) and NCC with combustor heat release.

5. Core engine model with reacting flow in combustor.

6. Full engine model; coupled APNASA turbomachinery simulation to NCC model of combustor.

Multidisciplinary Applications and Dynamic Engine Simulations (Phase II)

Karl Owen
NASA Glenn Research Center
Cleveland, Ohio

Outline
(Multidisciplinary Applications)

- Spectrum
  (PI: Dr. Evangelos Spyropoulos)

- Secondary Drum Flow

- Inlet/Engine Coupling

Objective

- Current industry practice is to couple several codes manually to find the answer to the entire problem solution space. This is time consuming and difficult.
- Use a multidisciplinary code to explore conceptually simpler methods for obtaining the problem solution.

Significance of Spectrum Approach
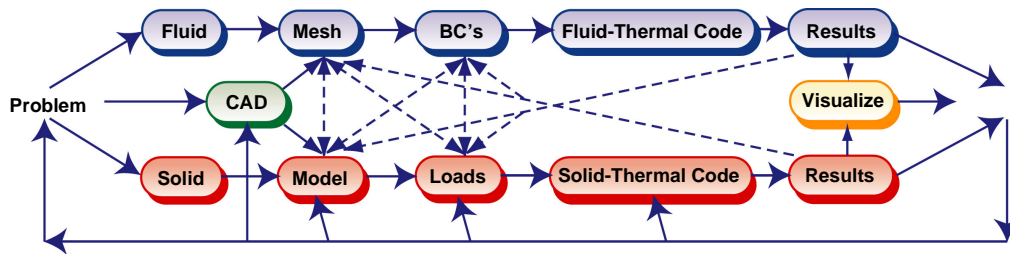
Loosely Coupled/Process Coupled Approach
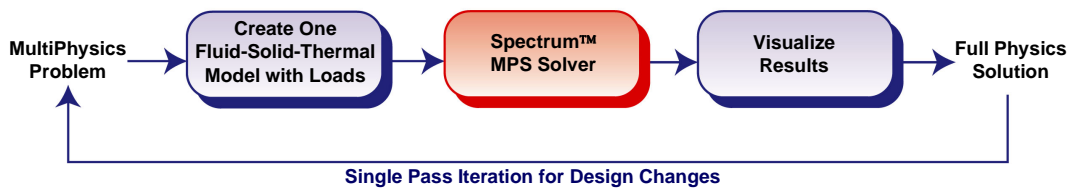
Single Pass Iteration for Design Changes

Spectrum Approach

Fully Coupled Multiphysics Simulations/Spectrum

Approach

- Identify and implement code enhancements required for propulsion system applications.

- Assess potential use of code as an industry tool for multidisciplinary simulations:

  - Centrifugal compressor fluid flow with Allied Signal using an AlliedSignal designed compressor.

  - Centrifugal compressor fluid flow with GRC using an Allison designed compressor.

  - Aero-mechanical cascade simulation with GRC data.

Centrifugal Compressor

Geometry
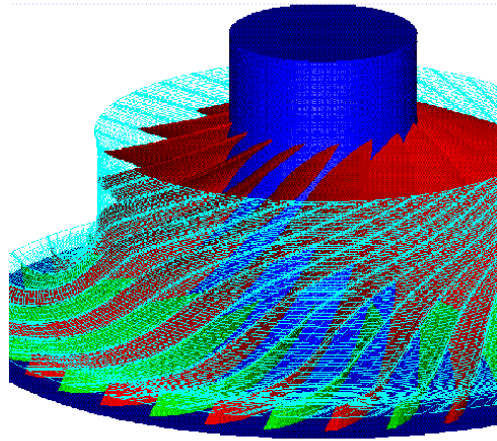
Geometry:

- 17 main blades
- 17 splitter blades
- Axial length = 3.64*in.*
- Outer diameter = 8.4*in.*
- Tip clearance = 0.0033*in.* - 0.0120*in.*

ANSYS

Centrifugal Compressor

Pressure contours

SPECTRUM   DAWES
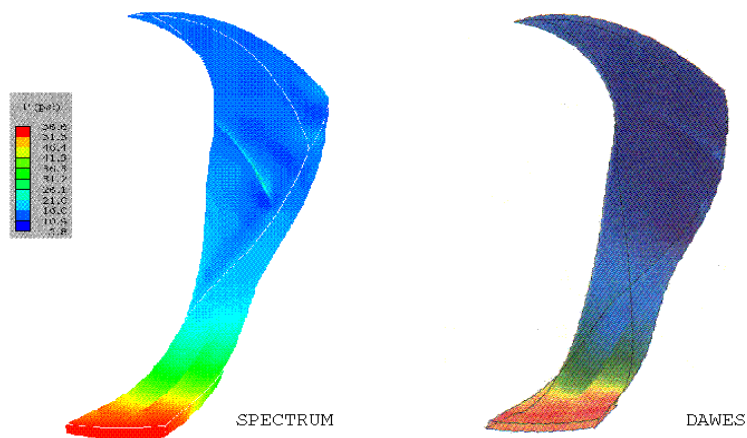
ANSYS

Results of Different Boundary Conditions
For AlliedSignal Centrifugal Compressor

AlliedSignal Compressor
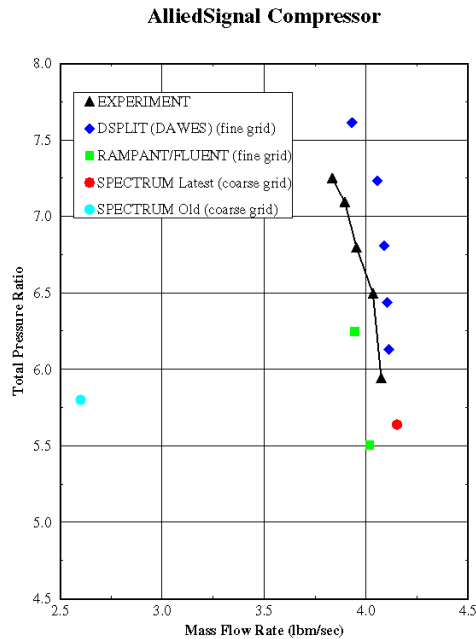
Accomplishments

- Evaluate new boundary condition approach

    – Perform course grid simulation

    – Compare with simulation that employed a uniform inlet velocity and temperature BC

    – Compare with experimental data

- Develop thermal wall functions

- Coarse and fine grid computations of the Allison Engines impeller with wall functions and comparison with data

- Final report

Outline

- Spectrum

- Secondary Drum Flow
  (PI's Dr. Meng-Sing Liou & Dr. Kumud Ajmani)

- Inlet/Engine Coupling

Objective

- Current industry practice for evaluating secondary (rotor drum flows) is crude, using 1-D or empirical models.

- Industry has indicated that commercial codes are inadequate for secondary flow solutions.

- Develop an accurate & efficient simulation capability employing aero-thermal coupling techniques for secondary flow systems in gas turbine engines.

- Assess potential use of the code as an industry tool for secondary flow simulations.

Approaches

- Systematic Computational Approach Using:
  - An industry-standard, well-supported CFD Code (OVERFLOW)
  - An innovative gridding technique (CHIMERA/PEGSUS)
  - Parallel solution techniques (PVM/MPI) on SGI workstations
- To obtain multi-discipline solutions targeted to:
  - Coupling of flow and heat transfer solutions in secondary-flow systems
  - Simplifying geometry-to-grid mapping for complex geometries
  - Providing industry specific application platforms and solutions

GEOMETRY
C Grid / H Grid
384x41 / 120x84
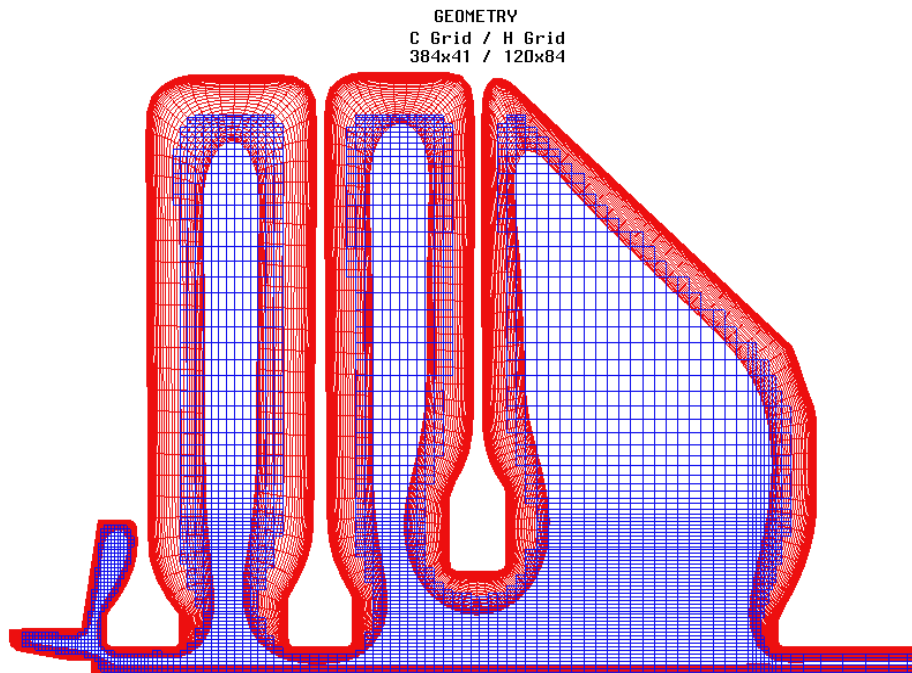
VELOCITY
C Grid / H Grid
384x41 / 120x84

0.154   MACH
-90.00EG   ALPHA
1.43x10**6Re
4.01x10**5TIME
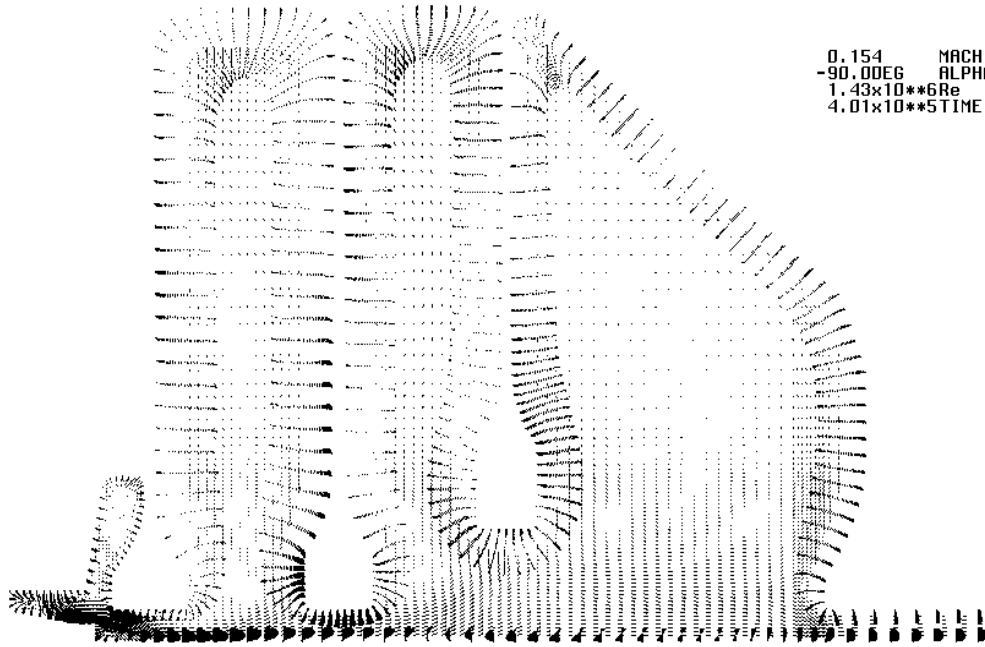
MACH NUMBER
C Grid / H Grid
384x41 / 120x84

CONTOUR LEVELS
0.05000
0.06000
0.07000
0.08000
0.09000
0.10000
0.11000
0.12000
0.13000
0.14000
0.15000
0.16000
0.17000
0.18000
0.19000
0.20000
0.21000
0.22000
0.23000
0.24000
0.25000
0.26000
0.27000
0.28000

0.154   MACH
-90.00EG   ALPHA
1.43x10**6Re
4.00x10**5TIME
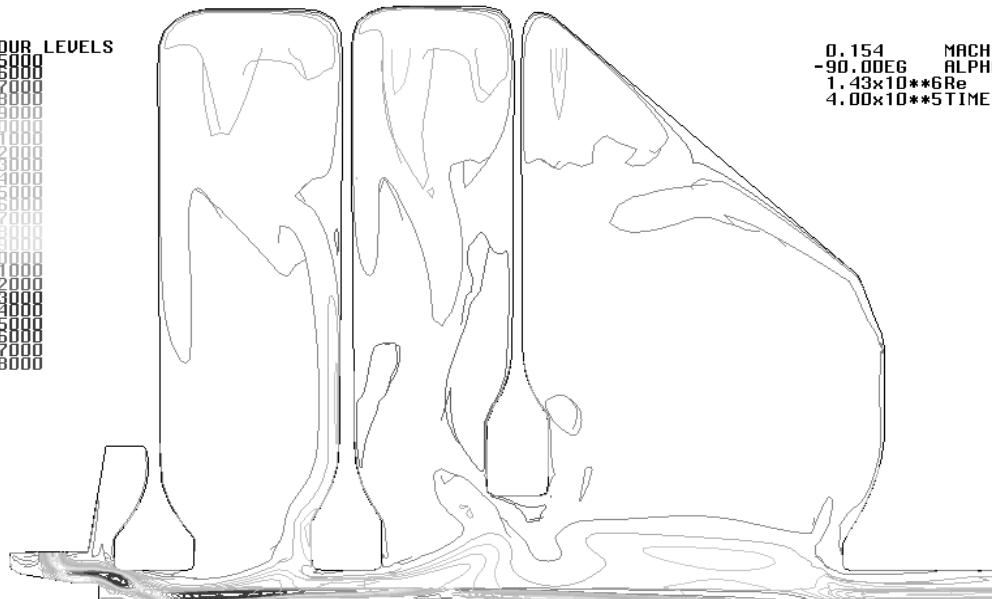
Accomplishments (FY99) and Plans (FY00)

- Couple the current CHT technology with industry-standard 2-D axisymmetric calculations for a GE-90 compressor geometry have been completed (CFD solutions and Conjugate Heat-Transfer)
- Detailed study of different geometry-mapping schemes reveals that a C-Grid/H-Grid combination is much better than multiple H-Grids
- Several standard, industry-strength tools (OVERFLOW for CFD, CHIMERA Grid-Tools and GRIDGEN) have been incoporated
- All computations are compatible with SGI/Origin Parallel Platforms

- Complete 3-D CHT calculations for the GE-90 Compressor geometry
- codes for structural analysis (NASTRAN etc.)

Outline

- Spectrum

- Secondary Drum Flow

- Inlet/Engine Coupling
  (PI's Dr. Ambady Suresh & Mr. Gary Cole)

Objective

- Identify and explore the difficulties associated with coupling codes of different types and fidelity levels.

- Formulate a more realistic compressor-face boundary condition for use with CFD simulations of inlets.
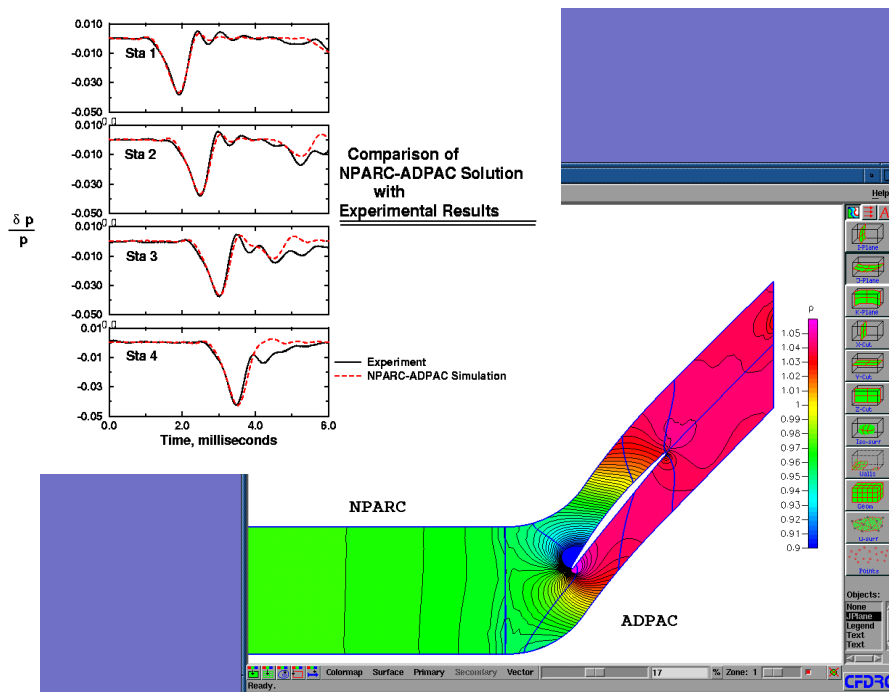
Comparison of reflected pulse simulation results with experimental data
from U. Cincinnati Inlet–Compressor Interaction Experiment
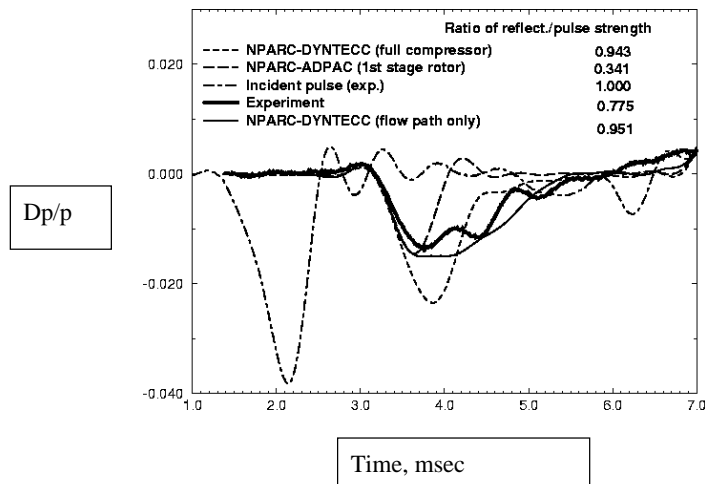
Accomplishments (FY99) and Plans (FY00)

- Demonstrated coupling of the NPARC simulation of the inlet with the ADPAC simulation of the first stage rotor used in the University of Cincinnati experiment with the following:

  - Inviscid-Viscous (mismatched) grids

  - Axisymmetric NPARC to 3D ADPAC

- Significant computational speedup by means of parallel processing

- Demonstrated coupling of 3D NPARC to 1D dynamic compressor code (DYNTECC) for modeling of full T58

- Exploration of the simulation of additional compressor blade rows using ADPAC
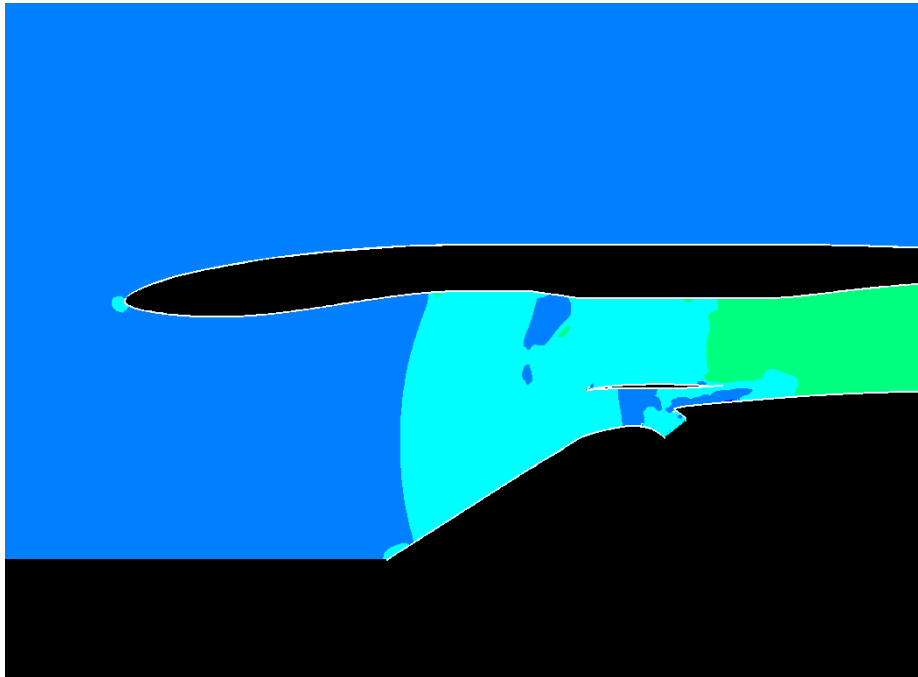
Outline
(Dynamic Engine Simulations)

- Fan Duct Overpressure Simulation
  (Dr. Mark Stewart)

- Dynamic Multidimensional Engine Simulations: AEDC

Objective

- Current industry practice for the prediction of fan duct over pressures are primitive, at best. This information is vital to the design of a safe aircraft.

- To develop an methodology to accurately predict the overpressure that might occur in a fan duct, thus allowing the efficient design of a safe yet effective engine fan duct/inlet.

Surge Pulse in EEE Fan Duct

Significance

- Develops methodology to make blade-off tests "non-events".

- Highlights 3-D NS capabilities in unsteady simulations of this type.

- Explores coupling, zooming, and dynamic simulation issues.

Outline

- Fan Duct Overpressure Simulation: Boeing Cooperative Agreement

- Dynamic Multidimensional Engine Simulations: AEDC (PI's Dr. Alan Hale, Ms. Jackie Chalk, Mr. Jason Klepper, Dr. Milt Davis)

Objective

- Develop a unique, full engine, multidimensional dynamic simulation capability that will allow detailed operability studies and the ability to include greater attention to operability issues in the design process.

- This technology will be non-proprietary and will be incorporated into the NPSS structure.

Three-Stage Military Fan
Opposing Pt and Tt Inlet Distortion
Analysis Plane -- Exit of the Last Rotor

Norm. Stag. Press. **Norm. Stag. Temp.**
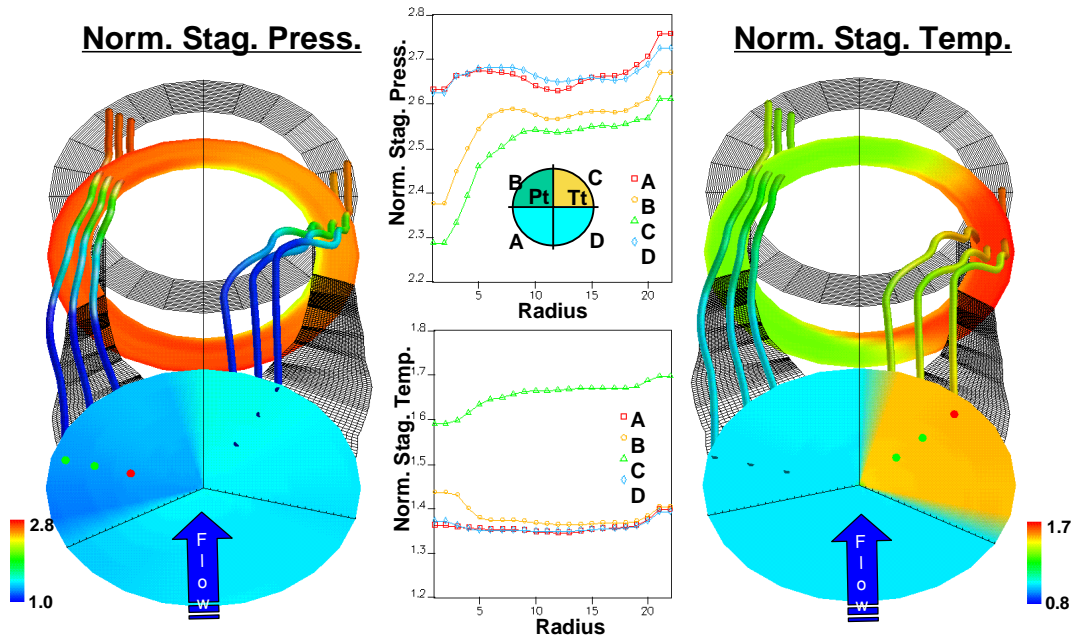
Summary

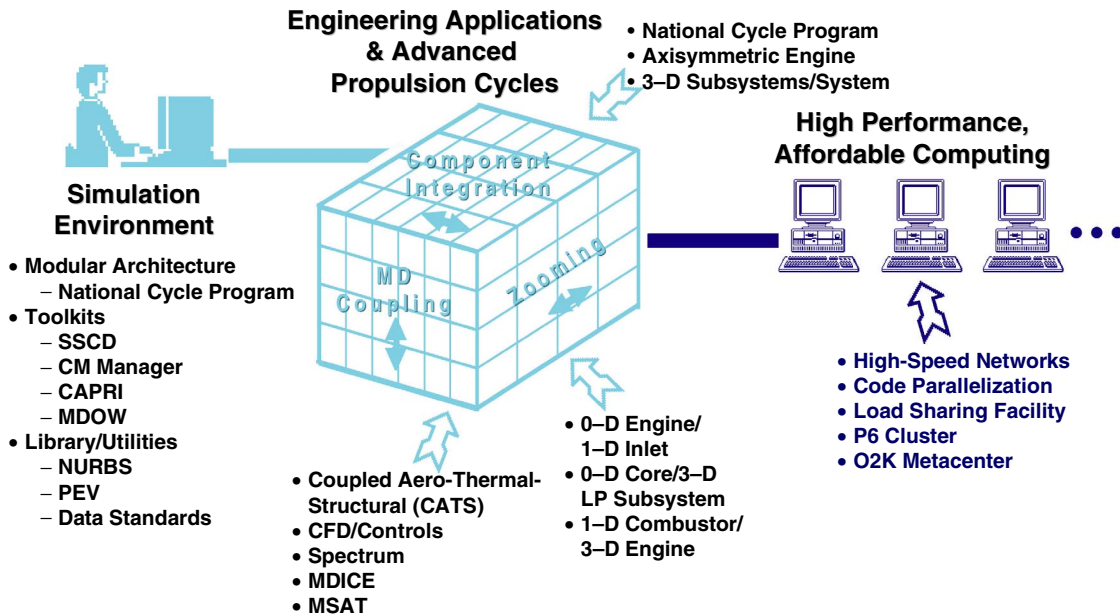- Ready for Implementation to Enhance AEDC Test Analysis
  - Types of Distortion (Steady,Transient, & Dynamic)
    - Pressure
    - Temperature
    - Combine Pressure and Temperature
  - Types of Machines
    - Multi Stage Fans
    - Multi Stage HPC
    - Dual Spool (FY00)
  - Current Computational Run Time Less than One Day

High-Performance Computing

Isaac Lopez

NASA Glenn Research Center

Cleveland, Ohio

Code Parallelization

- HPCCP/CAS Grand Challenge Level 1 Milestone
  - Demonstrate 200-fold improvements over FY1992 baseline in time-to-solution for Grand Challenge applications of TFLOPS testbeds (6/99)

- Two Codes at GRC accomplished this milestone
  - APNASA
  - National Combustion Code (NCC)

APNASA

APNASA is a computer code being developed by a government / industry team for the design and analysis of turbomachinery systems. Based on the Average-Passage model developed by John Adamczyk at the NASA Glenn Research Center.

Objective

- To develop a turbomachinery simulation capability that will provide a detailed analysis during the design process of gas turbine engines

Accomplishment

- The present effort has achieved an overnight turnaround (15 hours) of a full compressor simulation when using APNASA. This represent a 400:1 reduction in a full compressor simulation turnaround relative to 1992.

Plan

- To achieve a three hour turnaround of a full compressor simulation using APNASA by September of 2001. This will result in a 2400:1 reduction in turnaround time relative to 1992.
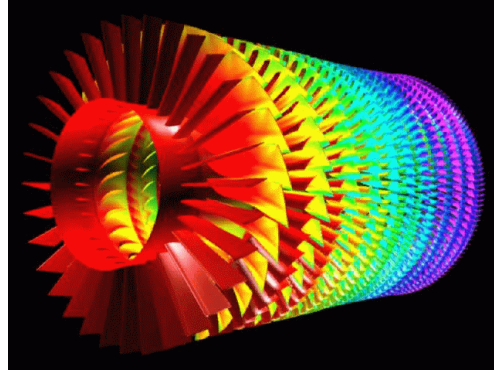

Significance

- The APNASA code can be used to evaluate new turbomachinery design concepts.

- When integrated into a design system, the code can quickly provide a high fidelity analysis of a turbomachinery component prior to fabrication. This will result in a reduction in the number of test rigs and lower development costs.

- Either APNASA or the methodology on which it is based has been incorporated into the design systems of six gas turbine manufacturers.

APNASA
Factors Influencing Turnaround Time
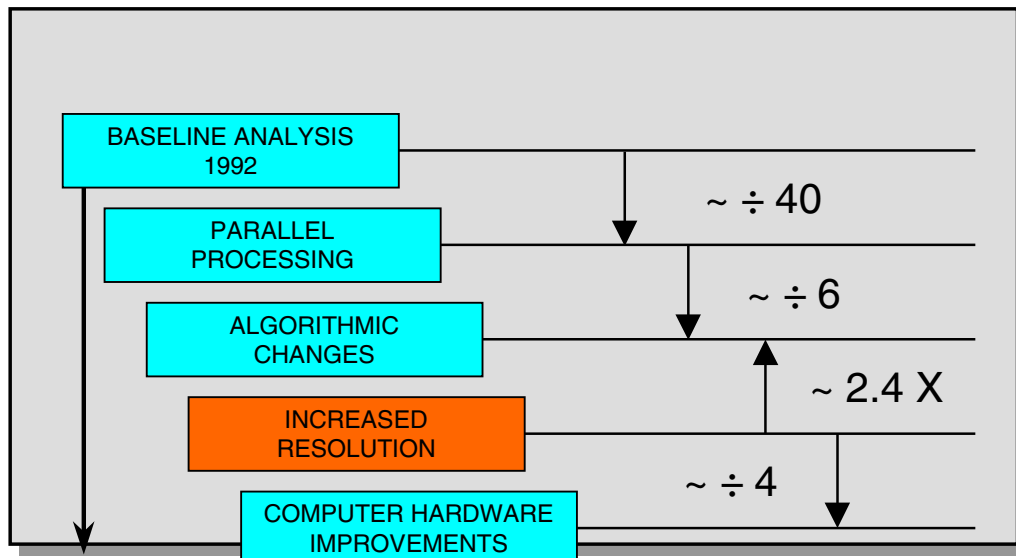
APNASA
Estimated Turnaround Time
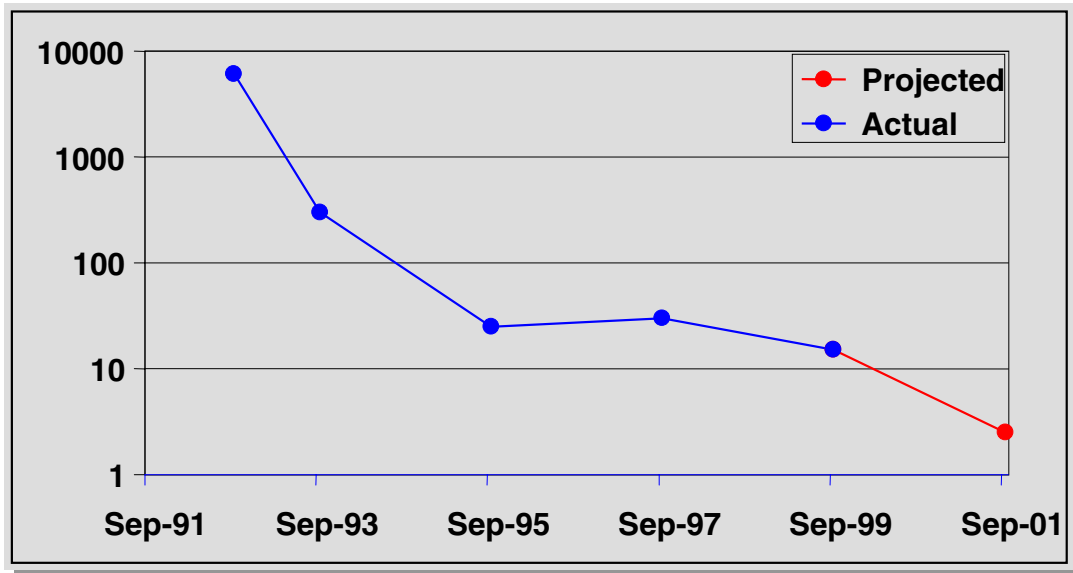
National Combustor Code

The National Combustion Code (NCC) is an integrated system of computer codes being developed by an industry/government team for the design and analysis of combustion systems.

Objective

- To develop a multidisciplinary combustor simulation capability that will provide a detailed analysis during the design process of combustors for gas turbine engines. The combustor code will enable the analysis of a full combustor from compressor exit to turbine inlet. This capability will reduce the time and cost of developing advance, low emission combustor.

Accomplishments

- Modified I/O usage to obtain improved scalability, allowing the use of up to 56 processors on CAS Testbed III (SGI Origin 2000).
- Achieved a full combustor simulation turnaround time of 320:1 relative to 1992.

Plan

- Achieve a three hour turnaround of a full combustor simulation (1.3 million elements) by September 2001, representing a 1000:1 reduction in turnaround time relative to 1992.
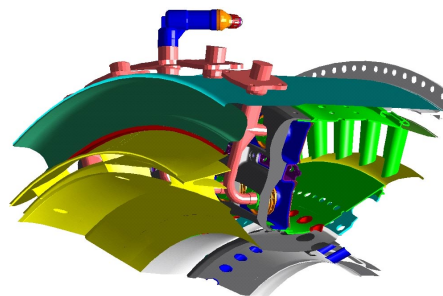
Significance

- The NCC system of codes can be used to evaluate new combustor design concepts. NCC can be integrated into a design system to provide a fast turnaround high fidelity analysis of a combustor, early in the design phase. The improved quality predictive analysis provided by NCC can result in improved confidence in the design, and a reduction of the number of hardware builds and tests thus reducing development time and cost. This capability will play a key role in meeting the national goal to reduce aircraft engine emissions.

Platform: SGI ORIGIN 2000 (250 MHz processors)
Version: CORSAIR 2.6.7

Test Cases:

LDI-MVS (971k elements)
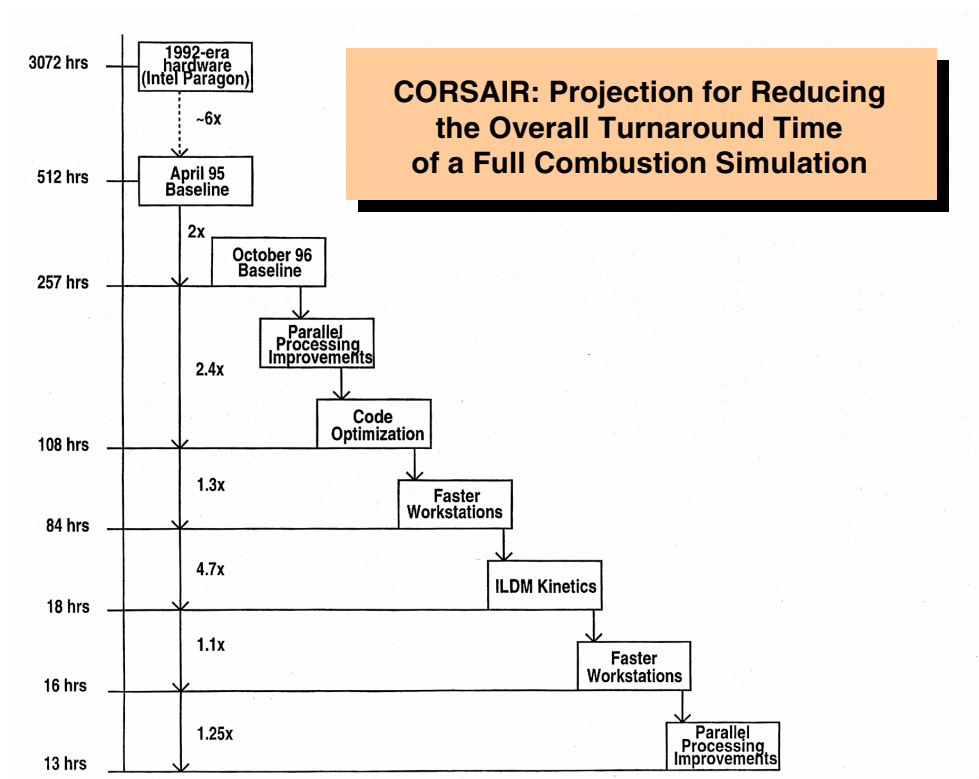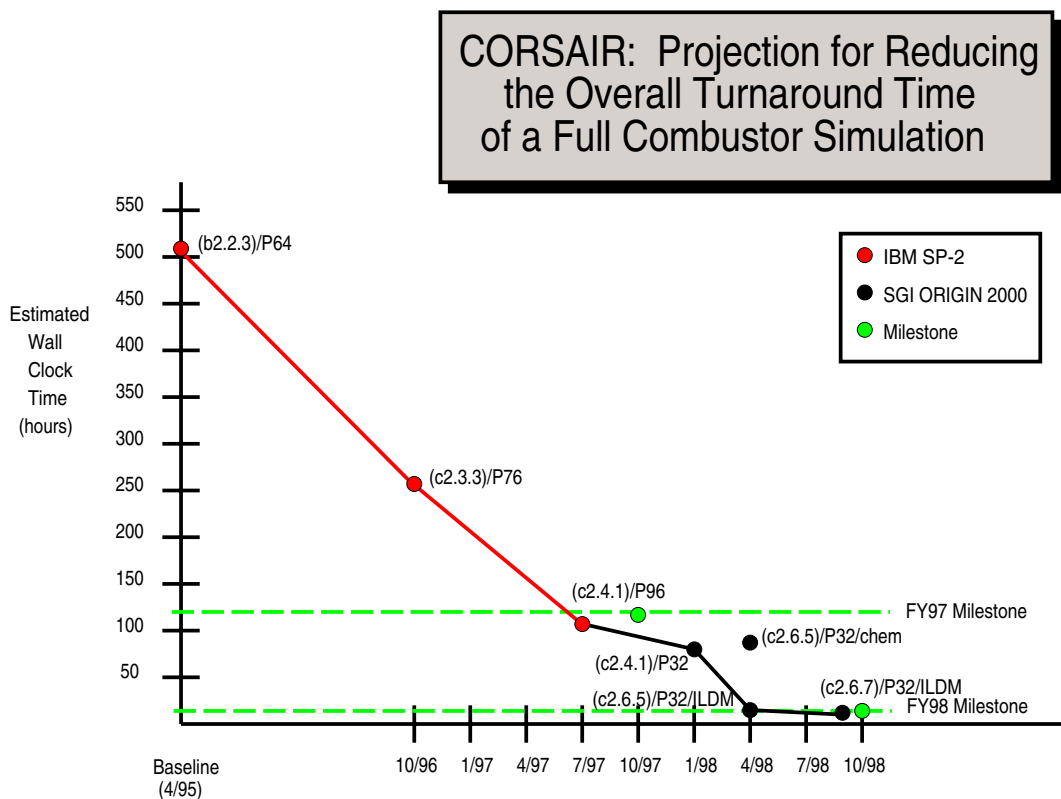**ILDM Kinetics Module**

Performance:
- **P32: 3.48 secs/iter**
- **13 hours to solution for "full-sized" problem**
- **Efficiency: 83.4%**

LDI-MVS (444k elements)
ILDM Kinetics Module

Performance:
- **P32: 1.55 secs/iter**
- **13 hours to solution for "full-sized" problem**
- **Efficiency: 79.5%**

3072 hrs	1992-era hardware (Intel Paragon)
	~6x
512 hrs	April 95 Baseline
	2x
257 hrs	October 96 Baseline
	2.4x Parallel Processing Improvements
108 hrs	Code Optimization
	1.3x
84 hrs	Faster Workstations
	4.7x
18 hrs	ILDM Kinetics
	1.1x
16 hrs	Faster Workstations
	1.25x
13 hrs	Parallel Processing Improvements

CORSAIR: Projection for Reducing the Overall Turnaround Time of a Full Combustion Simulation

CORSAIR: Projection for Reducing the Overall Turnaround Time of a Full Combustion Simulation

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Metacenter

- Primary testbed for NASA Information Power Grid (IPG) project.

- Currently there are 3 NASA Centers participating in the Metacenter.
  - AMES, GRC, LaRC

- Globlus system software is used as the super scheduler
  - It is installed and operational in the SGI Cluster and in the Pentium Cluster here at GRC.

- Demonstrated High Computing Efficiency with the Information Power Grid Concept through an NPARC Application Running at ARC and Glenn

IPG

- Computational Grids, e.g. IPG, will provide significant new capabilities to scientists and engineers by facilitating construction of information based problem solving environments / frameworks that knit together widely distributed computing, data, instrument, and human resources into just-in-time systems that can address complex and large-scale computing and data analysis problems arising from, e.g.:
  - coupled, multidisciplinary simulations;
  - use of widely distributed, federated data archives;
  - coupling large-scale computing and data systems to scientific and engineering instruments.

Distributed Simulation Environment
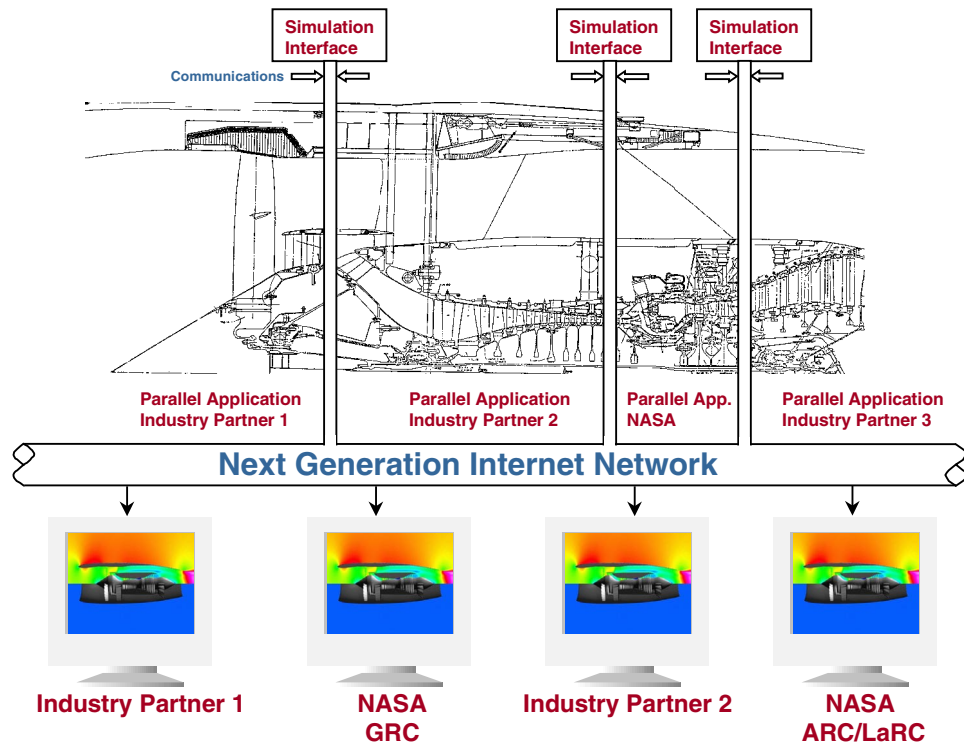
Globus

- The Globus project is developing the fundamental technology that is needed to build computational grids, execution environments that enable an application to integrate geographically-distributed instruments, displays, and computational and information resources. Such computations may link tens or hundreds of these resources.

- For more information go to http://www.globus.org/

NPARC
Globus test case

- The NPARC code was run over Globus for two test cases:

  - Rocket Based Combined Cycle engine simulation.

    - A 15 block case fairly well balanced with moderate communication.

  - F/A-18 Inlet simulation.

    - A 22 block case, poorly balanced, with significant communication.

- In both cases 16 NPARC processes were run, the first 4 on evelyn (ARC) and the other 12 on sharp (GRC).

NPARC
Globus test case

- Computing Requirements
- Memory
  - Each RBCC process requires about 172 MB.
  - Each F/A-18 process requires about 144 MB.
- Storage
  - Total RBCC file storage is 214 MB.
  - Total F/A-18 file storage is 171 MB.
- RBCC Network load
  - 210 messages/iteration, about 20 messages/second.
  - 17.8 MB/iteration, about 1.7 MB/second.
- F/A-18 Network load
  - 980 messages/iteration, about 100 messages/second
  - 15.9 MB/iteration, about 1.6 MB/second.

NPARC
Globus test case

- There was a considerable per-iteration variability in elapse time. This is possible due to the network between evelyn and sharp

- When evelyn/sharp case runs well, it's quite close to sharp-only run. So it seems that a consistently good network would allow this application to run well when spread between sites.

CORBA and GLOBUS
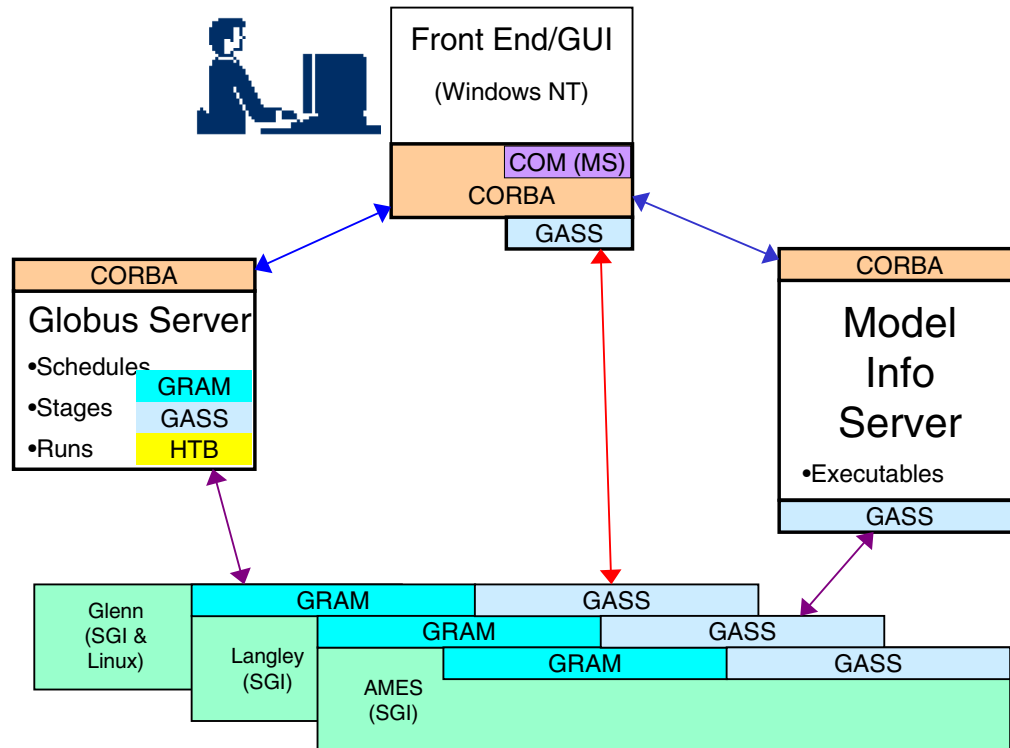
Pentium II Cluster

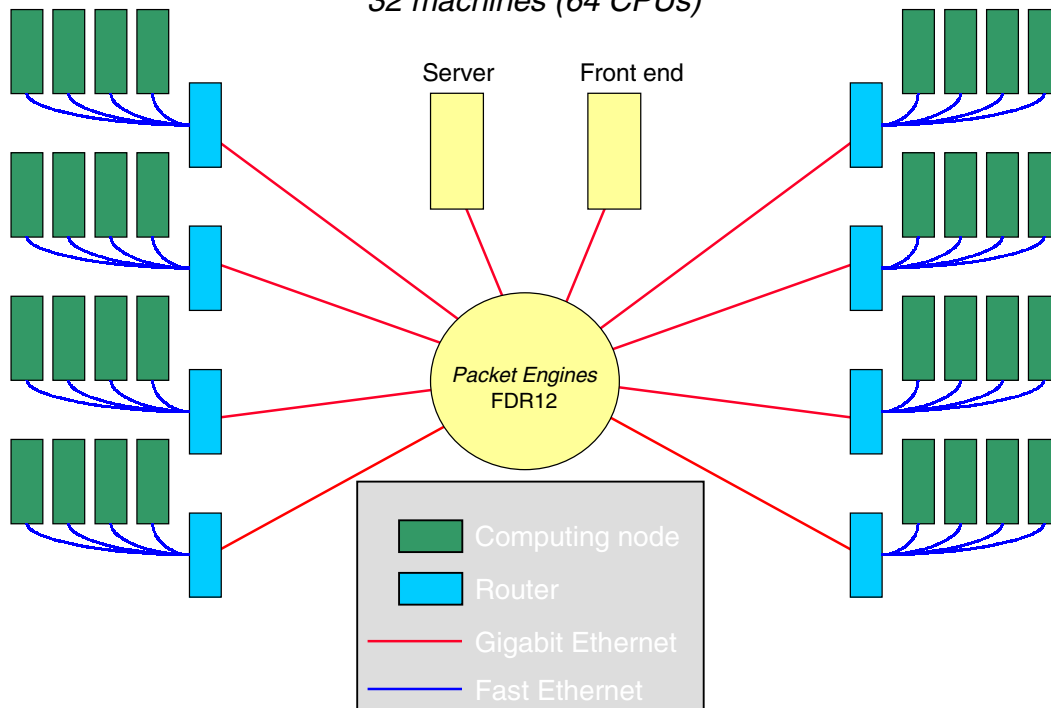## Accomplishment

- Initiated the Use of the Pentium Cluster to Execute Significant Turbomachinery Simulations in a Production Mode

Pentium II Cluster
Computing Nodes

- Hardware
- 2 Pentium II (Deschutes) 400MHz CPUs
- 512 MB RAM
- 2048 MB Swap
- 8GB local disk
- Fast Ethernet
- Debian Linux 2.0

- Software
- Portland Group Compilers V3.0
  – C, C++, F77, F90, HPF
- MPICH
- PVM3
- LSF
- Globus

Pentium II Cluster Network Architecture
32 machines (64 CPUs)

Server

Front end

Packet Engines
FDR12

Computing node
Router
Gigabit Ethernet
Fast Ethernet

SGI Origin 2000 System

- Hardware
- Twenty four processors
    - 16 250 MHz
    - 8 195 MHz
- 4.6 Gb memory
- 62 Gb internal disk storage
- 150 Gb external RAID disk storage
- 02 workstation serially-attached as console
- Fast Ethernet (100 Mb/sec) networking

- Software
- IRIX 6.5.4
- Compilers
    - IRIX Development Environment 7.3:
        - Fortran 77
        - Fortran 90
        - C
        - C++
    - Java Execution & Development Environment, Version 1.2
- Applications: CaseVision, RapidApp, ShowCase
- LSF, Globus

Affordable High Performance Computing

Level 1 Milestone (GC3)

Demonstrate end-to-end reductions in cost and time to solution for aerospace design applications on heterogeneous systems.

Accomplishments

- Steady state compressor solver speedup is 2.5X.
- Turnaround time for 11.5 stage high-pressure compressor simulation is 1.8 days on a cluster of SUN workstations.
- Fine-grain parallelization of unsteady compressor solver using Prowess & PVM message passing software completed.
- Whole compressor viewing capability available in pV3 Gold visualization package.

Significance

- The achievement of overnight turnaround for the proposed Grand Challenge problem for aerospace propulsion applications will lead to reduced cost and shorter time to market for aeroengines.

Metrics

- Overall design and development time for the high pressure compressor will be reduced from 18 months to 14 months by September 30, 1997 which translates into a savings of $3.33 million (22% of 18 month cost). A final design & development time of 12 months will be reached by September 30, 1998 (total savings of $5 million and 33% time reduction).
- The detailed analysis time for the compressor simulation was reduced from 50 days to 1.8 days by September 30, 1999.
- Performance rate will be at least 5GFLOPS as achieved on the Cray C90. Actual rated needed on cluster is 50GFLOPS.

Affordable High Performance Computing

Level 1 Milestone (CT6)

Demonstrate cost effective high-performance computing at performance and reliability levels equivalent to 1994 Vector Supercomputers at 25% of the capital cost.

Accomplishments

- Benchmarking of applications completed on Cray C90, IBM SP2, DEC Alpha & SUN workstation clusters.
- Cost comparison between Cray C90 and SUN workstations at equivalent performance levels completed with a 92% reduction in computing cost demonstrated with networked workstations (exceeded 75% reduction goal).
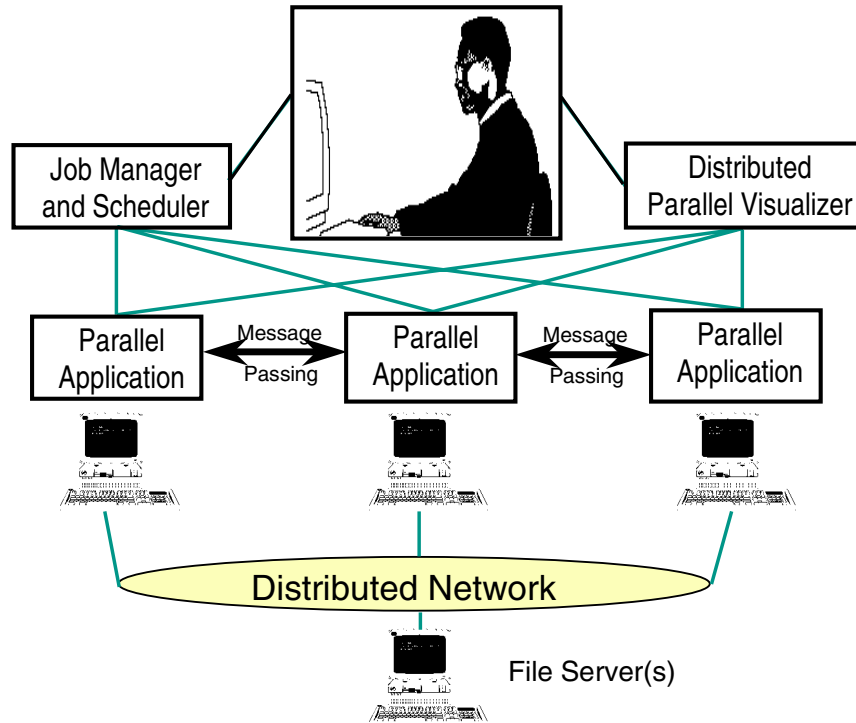
Significance

- A distributed workstation network is a cost-effective, reliable high-performance computing platform for production use.

Metrics

- Maintain same reliability (99%) and performance levels on the workstation cluster as performed on the Cray C90.
- Cost of a workstation cluster equivalent in performance to the Cray C90 less than 25% the cost of the C90.

Platform	Number of Nodes	Hardware Costs	Network Costs	Server Costs	Maint Costs	System Admin Costs	Total Costs	Ratio of Costs
SUN Ultra 2 (1996)	10	$220,000	$11,440	$3,750	$15,000	$15,000	$265,190	7.64%
Cray C90 (1994)	1	$3,031,250	included in Hardware Costs	N/A	$300,000	$137,500	$3,468,750	

Integration of AHPC Products

Job Manager and Scheduler		Distributed Parallel Visualizer

Parallel Application	Message Passing	Parallel Application	Message Passing	Parallel Application

Distributed Network

File Server(s)

Major Milestones Status

2X Solver Speedup **Initial Checkpointing**	**9/30/95** **3/30/96**	**Achieved** **Complete for distributed analysis**
Parallel Visualization **Muliticluster Job Scheduling**	**6/30/96**	**pV3-Gold in Beta** **Scheduling demonstrated**
Parallelization of TURBO	**9/30/96**	**Code delivered to NASA Glenn**
Job Migration **Dynamic Job Scheduling**	**12/30/96**	**Both validated 9/30/97**
High Performance File System	**3/30/97**	**Complete** **Report delivered August 1998**
Parallel NASTRAN **Code Coupling in VCE**	**6/30/97**	**Demonstrated** **2 of 3 codes coupled Sept 1998**
Parallel Visualization **Parallel System Software**	**9/30/97**	**Complete pV3-Gold delivered** **Delayed – validation needed**
Computing across WAN	**12/30/97**	**Complete June 1999**
50:1 Speedup HPC **Overnight Resonance Stress**	**3/30/98**	**June 1999: Achieved 24:1 Speedup** **Complete June 1999**

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John Lytle, Greg Follen, Cynthia Naiman, Austin Evans,
Joseph Veres, Karl Owen, and Isaac Lopez

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John H. Glenn Research Center at Lewis Field
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13. ABSTRACT *(Maximum 200 words)*

The technologies necessary to enable detailed numerical simulations of complete propulsion systems are being developed at the NASA Glenn Research Center in cooperation with industry, academia and other government agencies. Large scale, detailed simulations will be of great value to the nation because they eliminate some of the costly testing required to develop and certify advanced propulsion systems. In addition, time and cost savings will be achieved by enabling design details to be evaluated early in the development process before a commitment is made to a specific design. This concept is called the Numerical Propulsion System Simulation (NPSS). NPSS consists of three main elements: (1) engineering models that enable multi-disciplinary analysis of large subsystems and systems at various levels of detail, (2) a simulation environment that maximizes designer productivity, and (3) a cost-effective, high-performance computing platform. A fundamental requirement of the concept is that the simulations must be capable of overnight execution on easily accessible computing platforms. This will greatly facilitate the use of large-scale simulations in a design environment. This paper describes the current status of the NPSS with specific emphasis on the progress made over the past year on air breathing propulsion applications. In addition, the paper contains a summary of the feedback received from industry partners in the development effort and the actions taken over the past year to respond to that feedback. The NPSS development was supported in FY99 by the High Performance Computing and Communications Program.

14. SUBJECT TERMS

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